

Continuations

High-Level Control Operators

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<http://www.hpi.uni-potsdam.de/swa/>

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A Program

```
makeOne
```

```
  | one |
```

```
  one := 1.
```

```
  ^ one
```

```
makeTwo
```

```
  | one |
```

```
  one := 1.
```

```
  ^ self makeOne + one
```

```
makeThree
```

```
  | one |
```

```
  one := 1.
```

```
  ^ self makeTwo + one
```

A Program

13 <76> pushCon stant: 1	14 <68> popIntoT emp: 0	15 <10> pushTem p: 0	16 <7C> returnTop
---	--	---	---

makeOne

17 <76> pushCon stant: 1	18 <68> popIntoT emp: 0	19 <70> self	20 <D0> send: makeOne	21 <10> pushTem p: 0	22 <B0> send: +	23 <7C> returnTop
---	--	--	--	---	---	---

makeTwo

17 <76> pushCon stant: 1	18 <68> popIntoT emp: 0	19 <70> self	20 <D0> send: makeTwo	21 <10> pushTem p: 0	22 <B0> send: +	23 <7C> returnTop
---	--	--	--	---	---	---

makeThree

A Program

17 <76> pushConstant: 1	18 <68> popIntoTemp: 0	19 <70> self	20 <D0> send: makeTwo	21 <10> pushTemp: 0	22 <B0> send: +	23 <7C> returnTop
makeThree						

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makeThree						

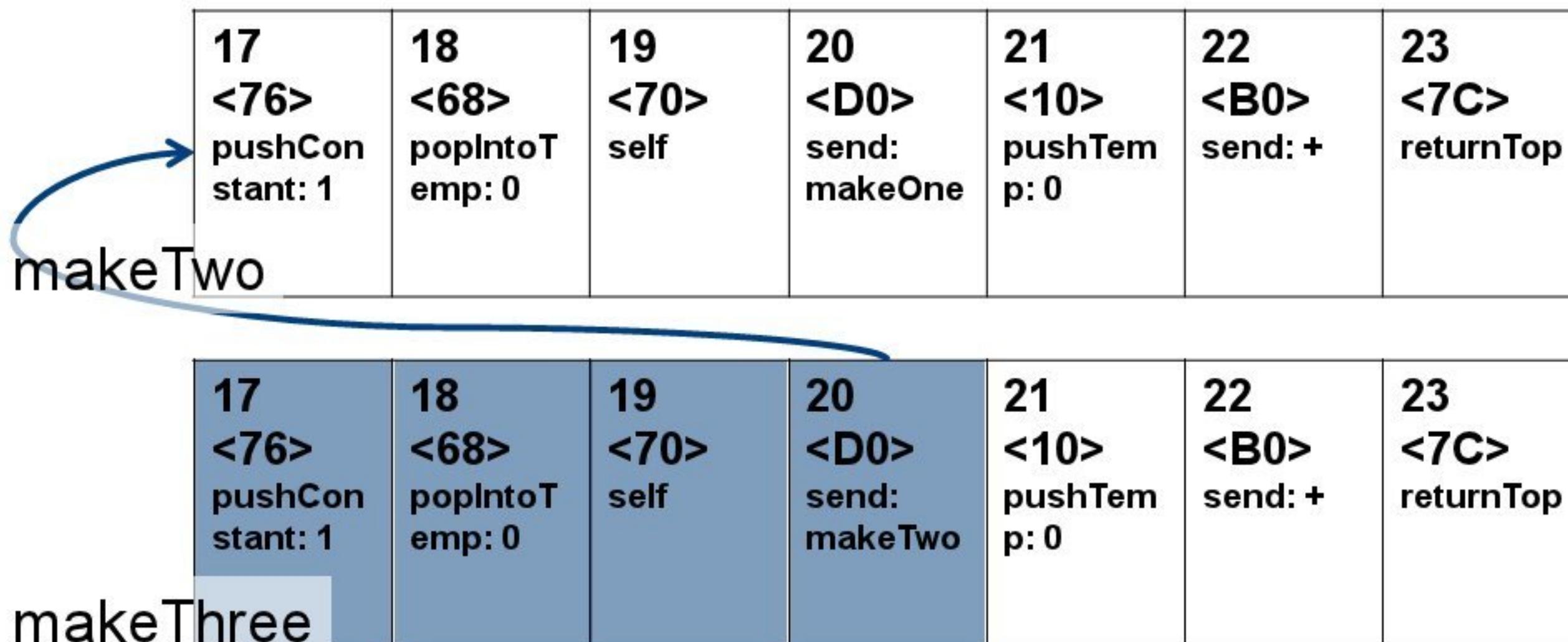
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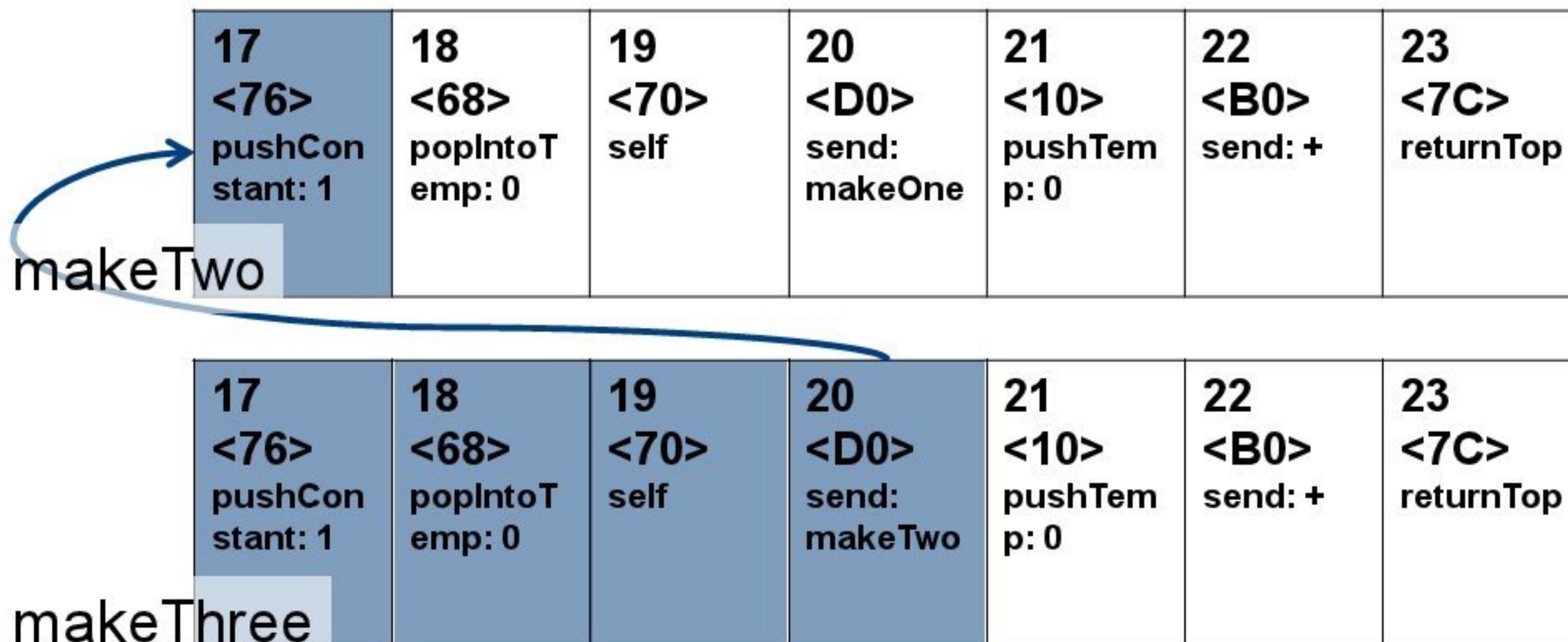
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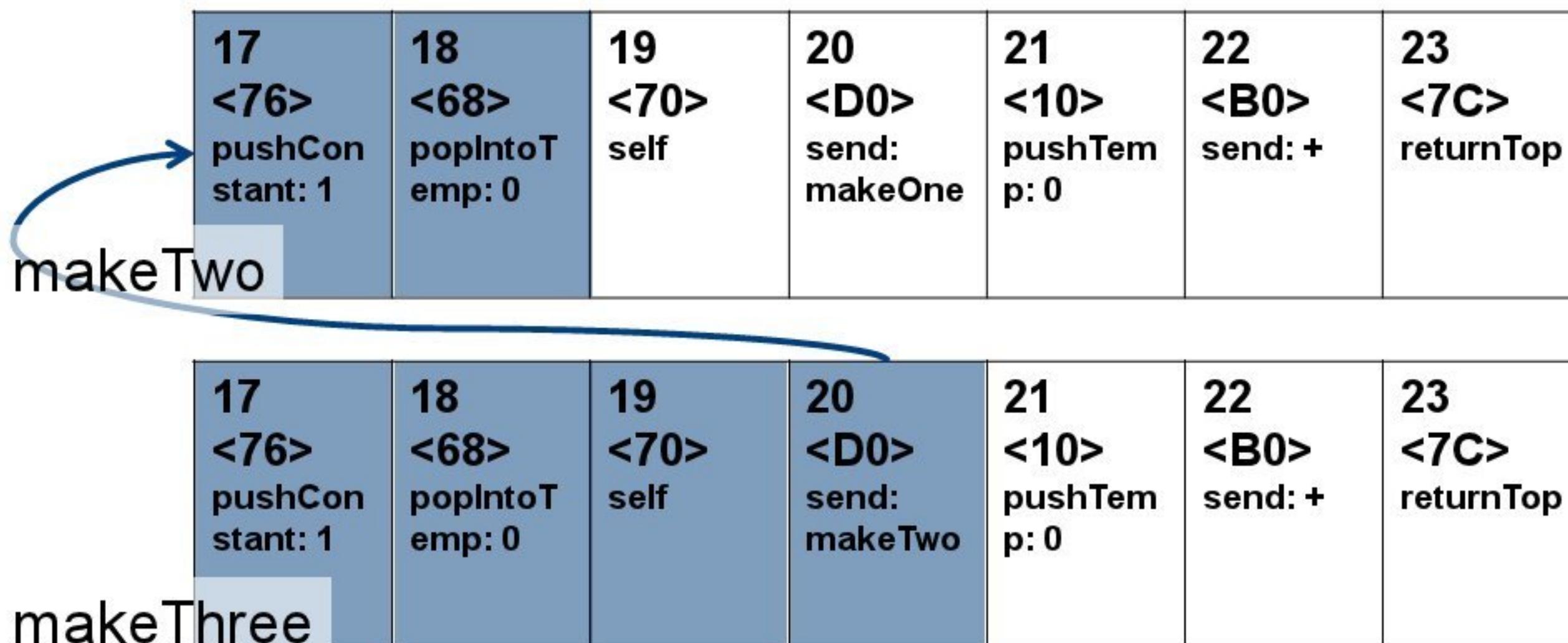
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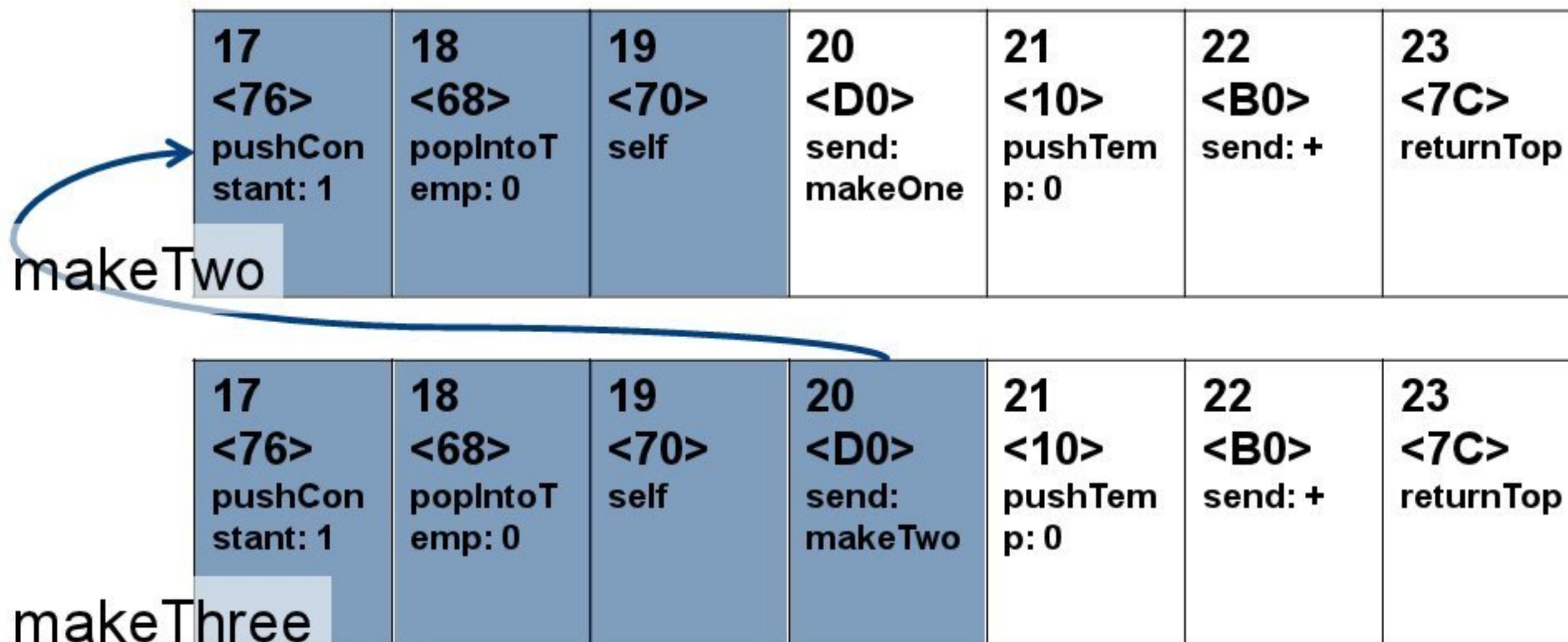
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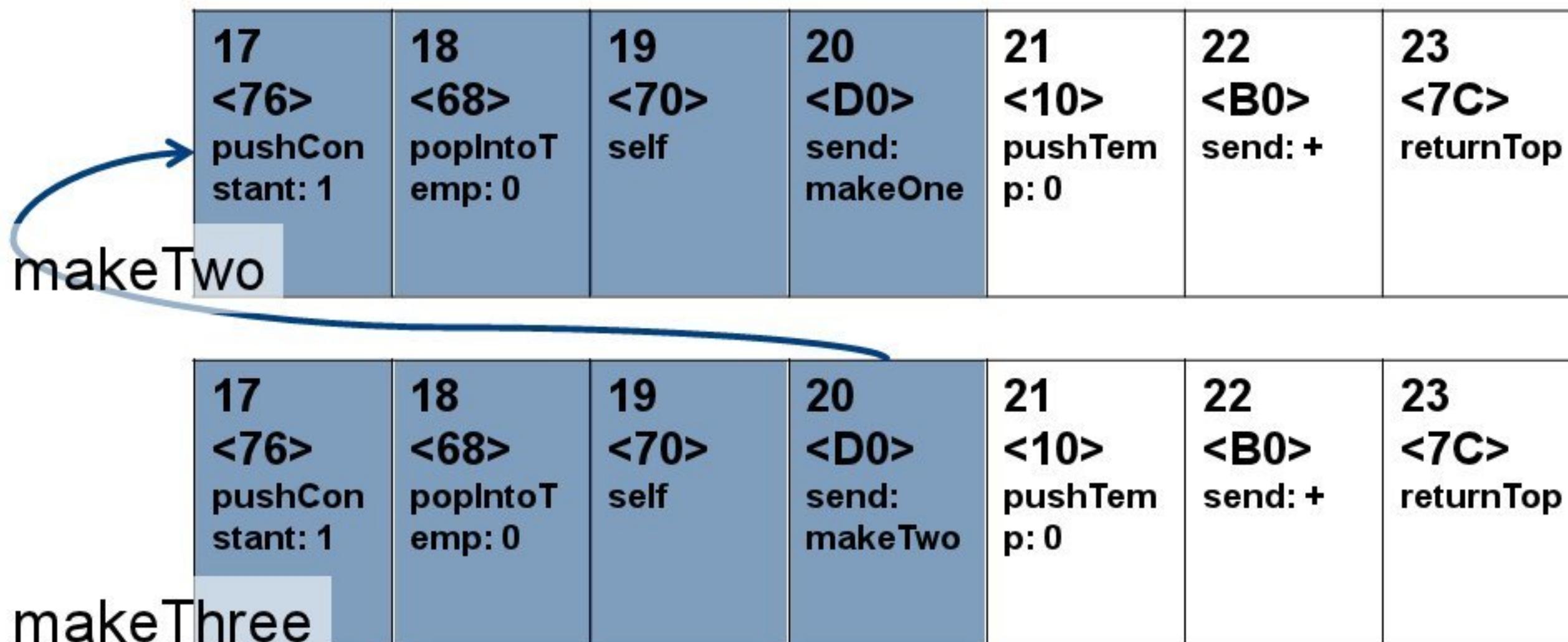
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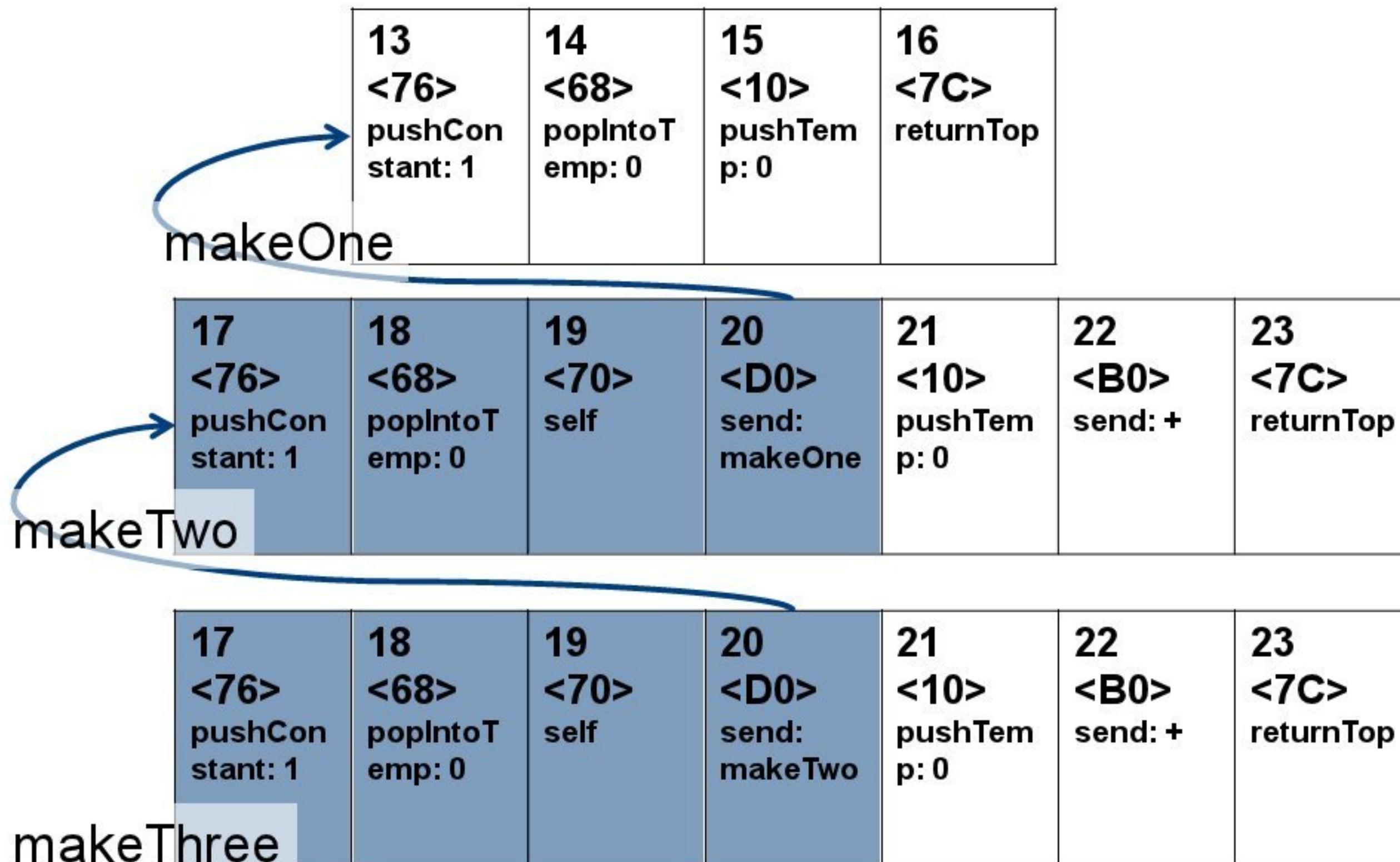
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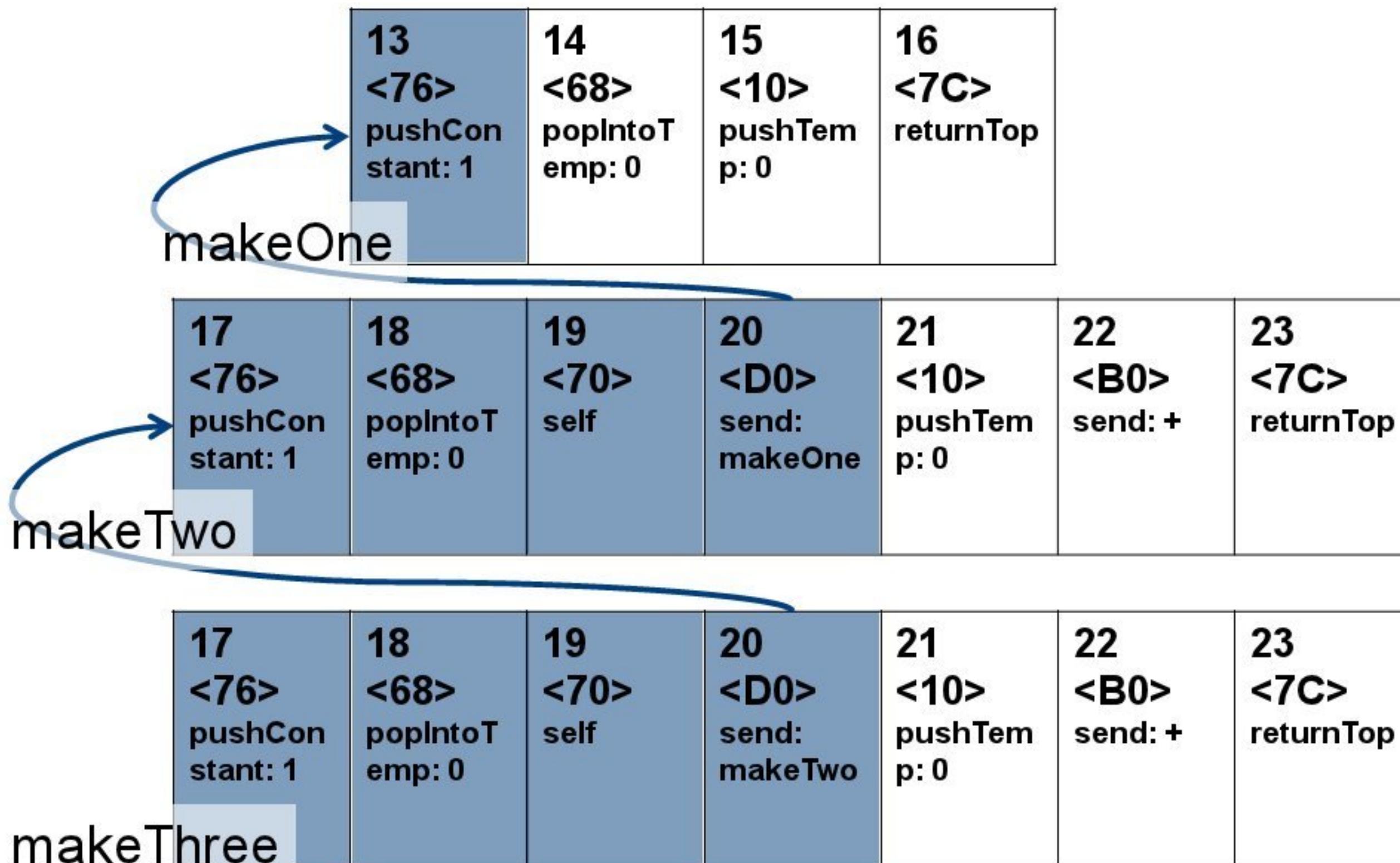
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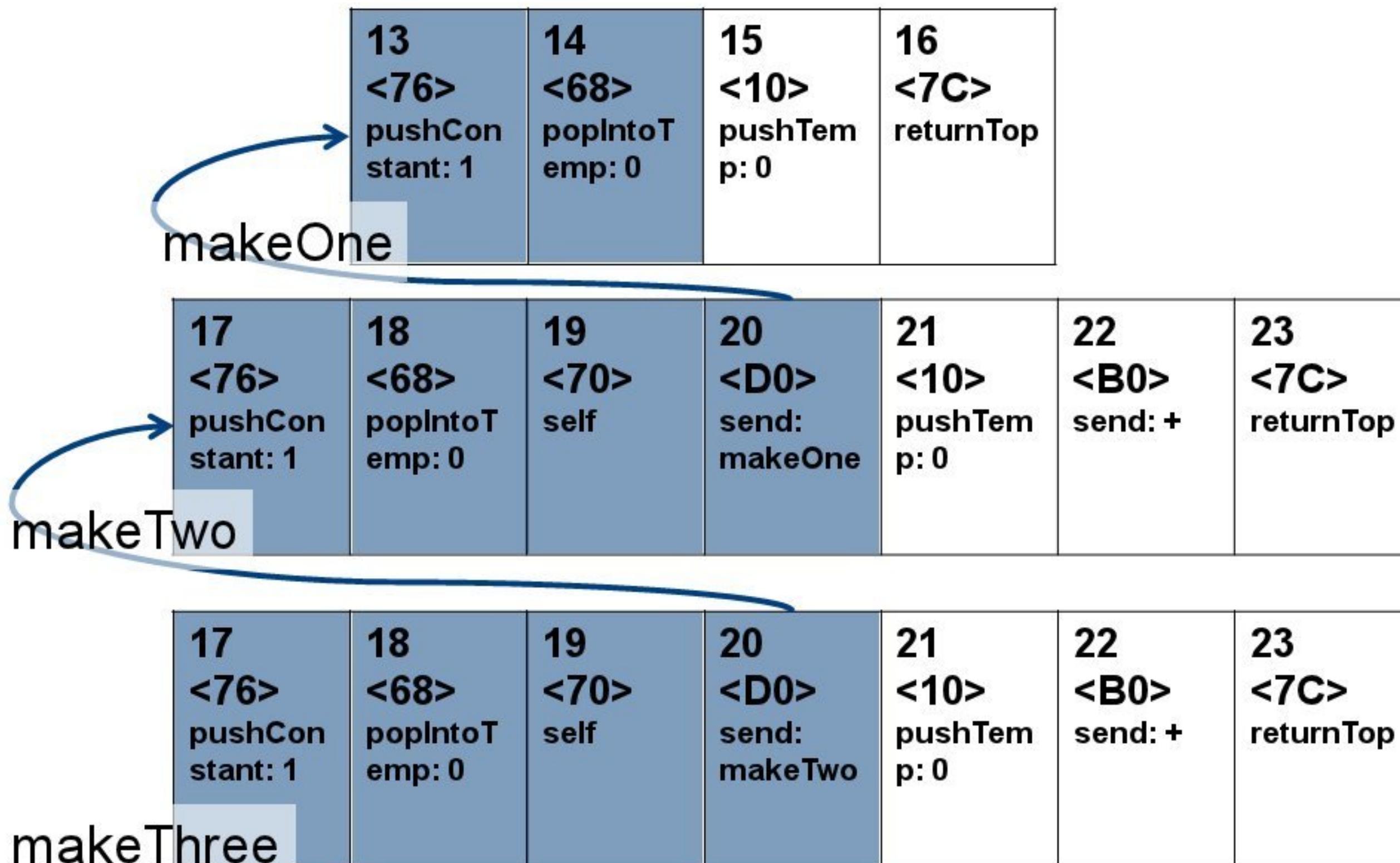
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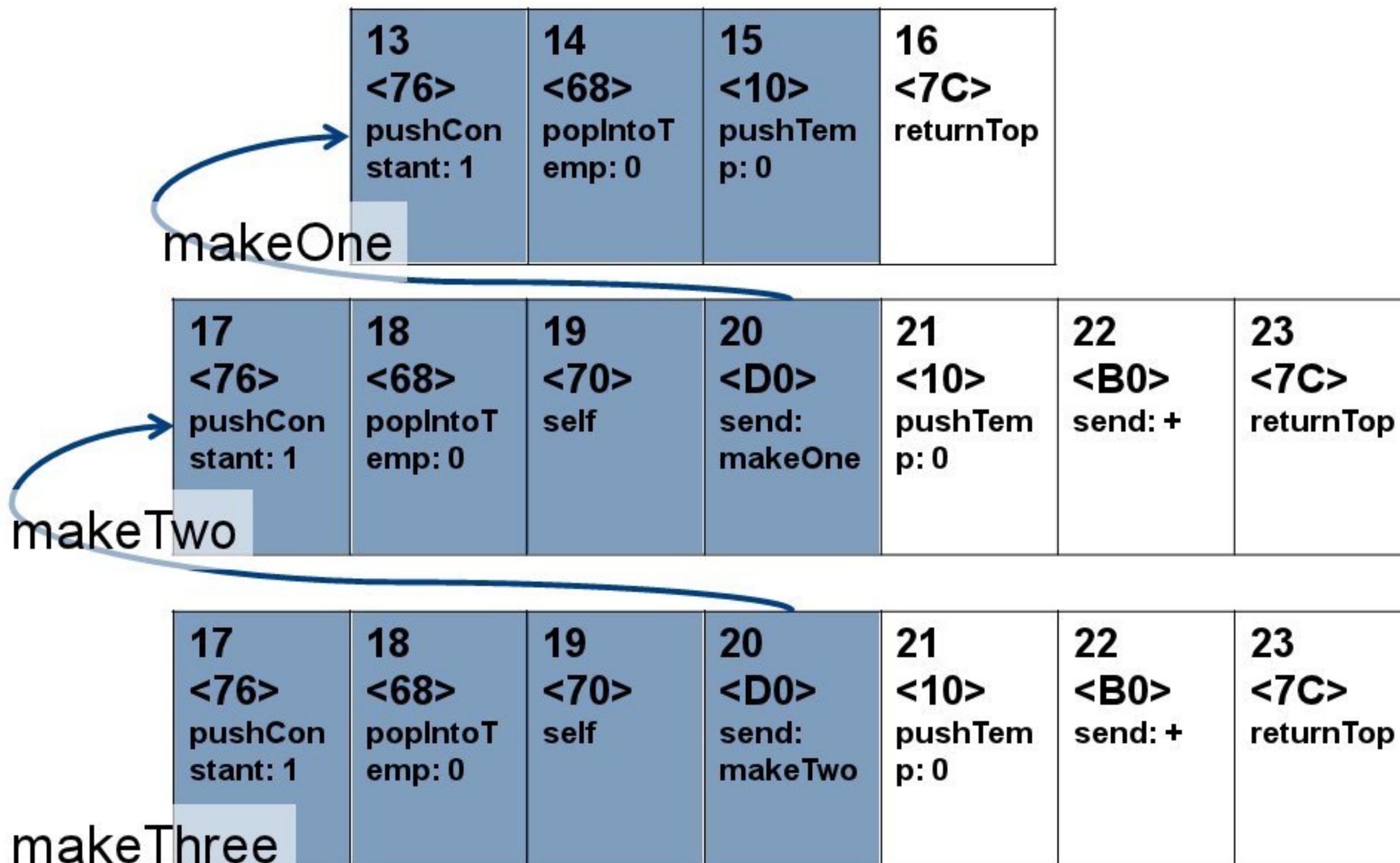
A Program



A Program



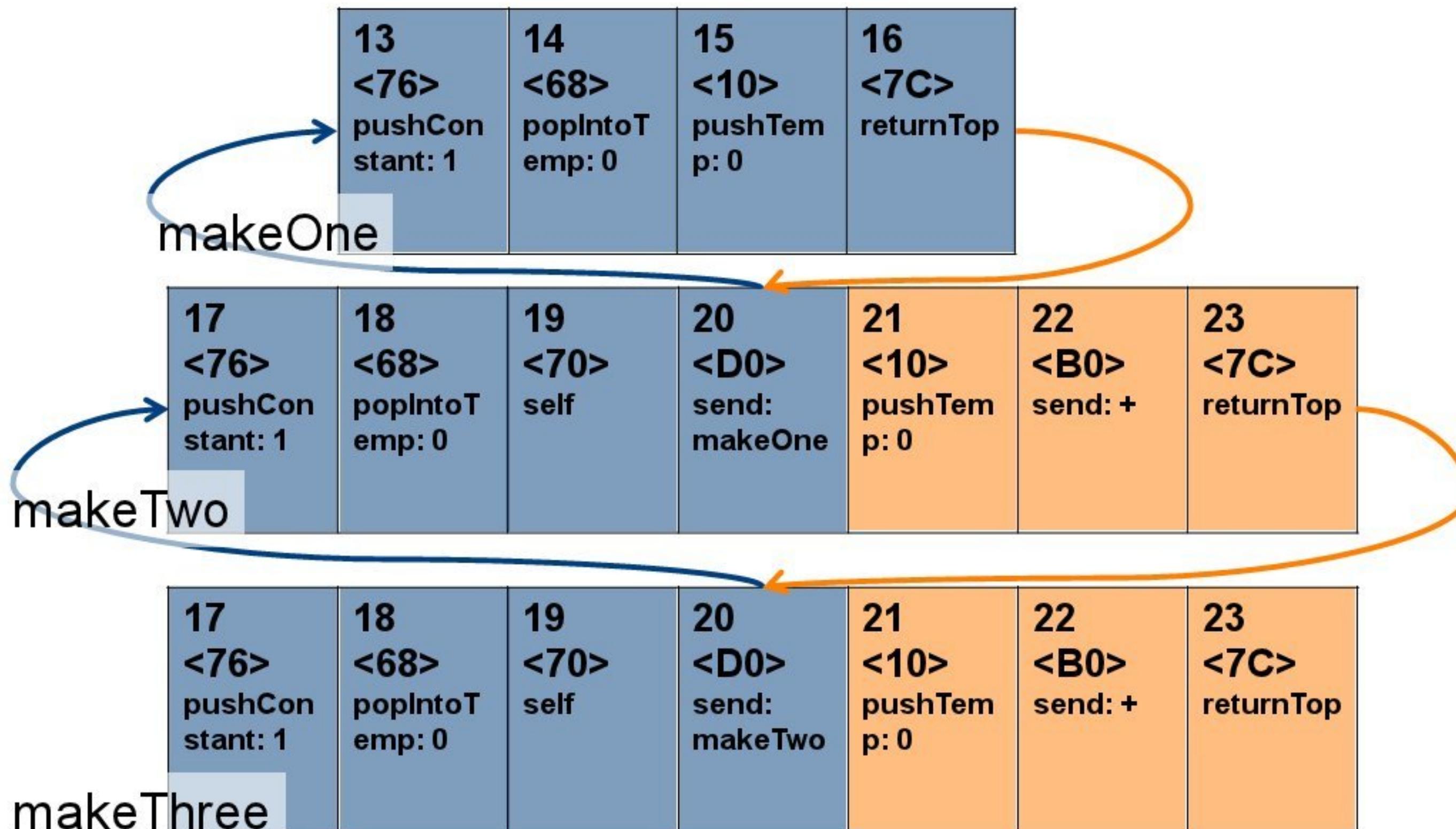
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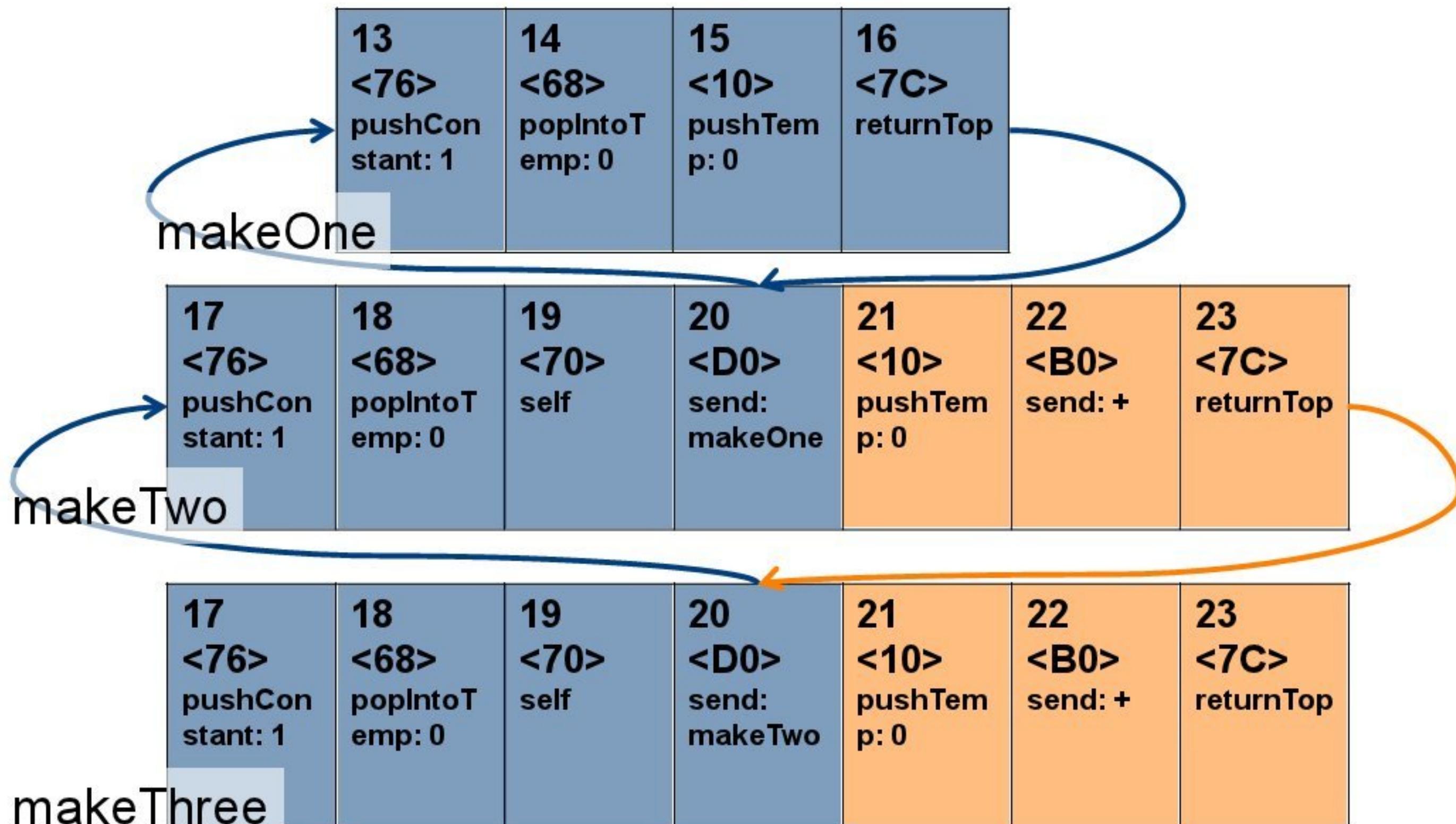
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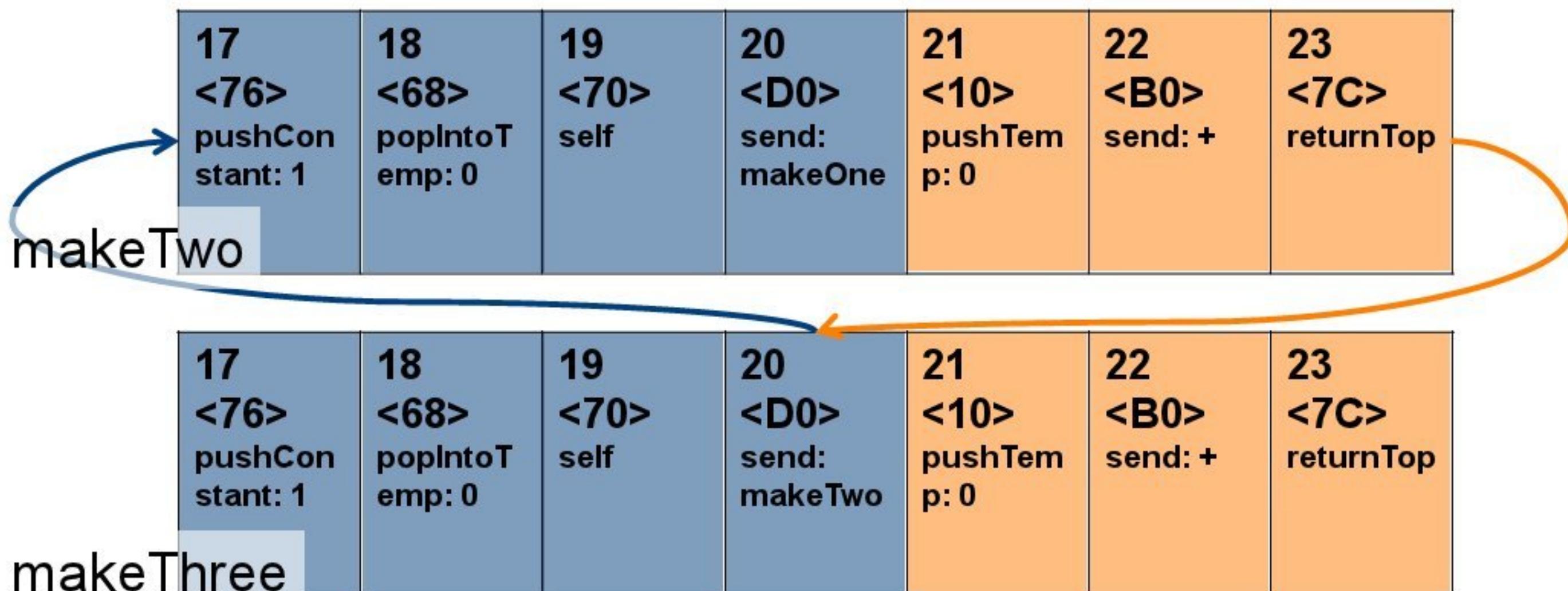
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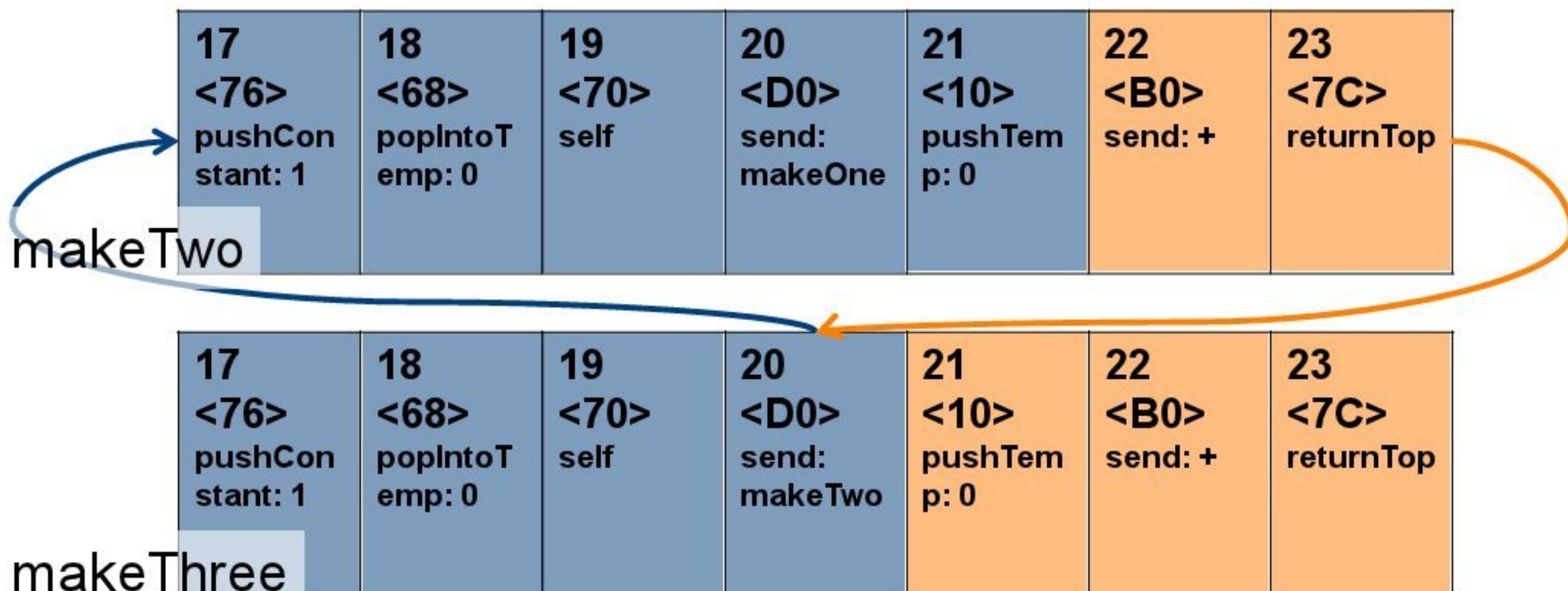
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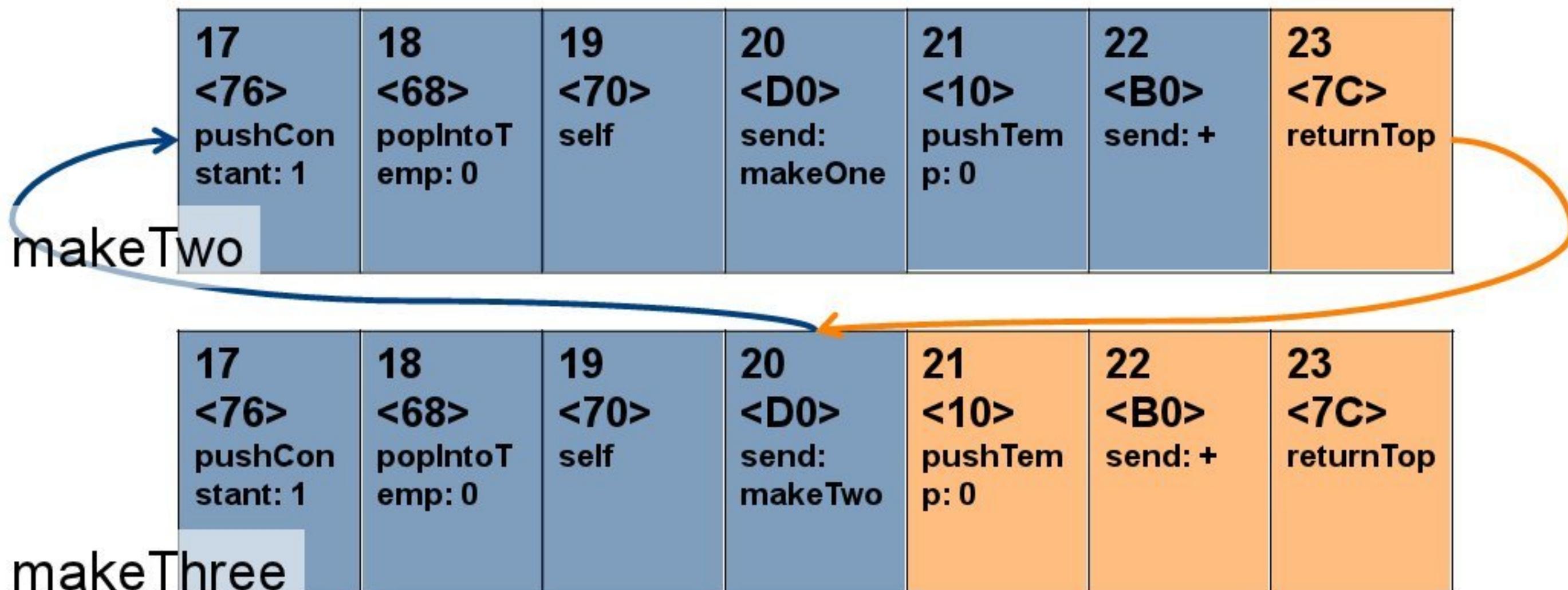
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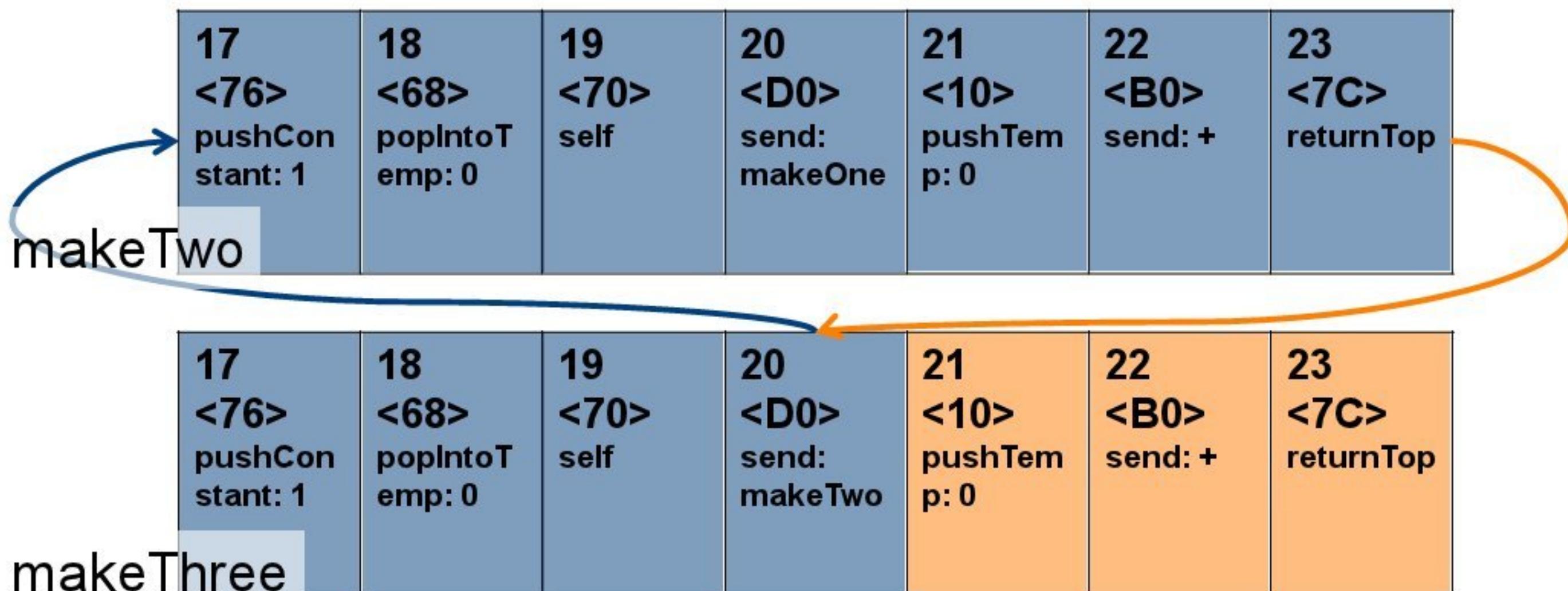
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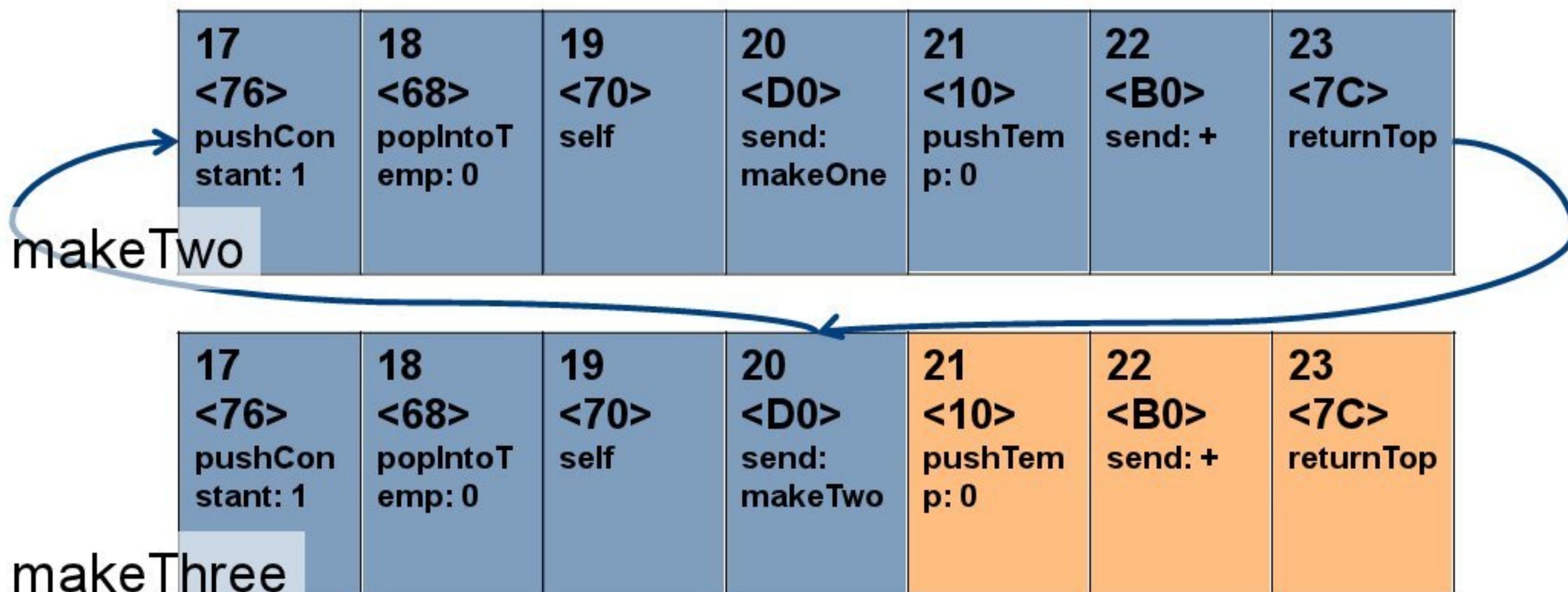
A Program



A Program



A Program



A Program

17 <76> pushConstant: stant: 1	18 <68> popIntoTemp: emp: 0	19 <70> self	20 <D0> send: makeTwo	21 <10> pushTemp: p: 0	22 <B0> send: +	23 <7C> returnTop
makeThree						

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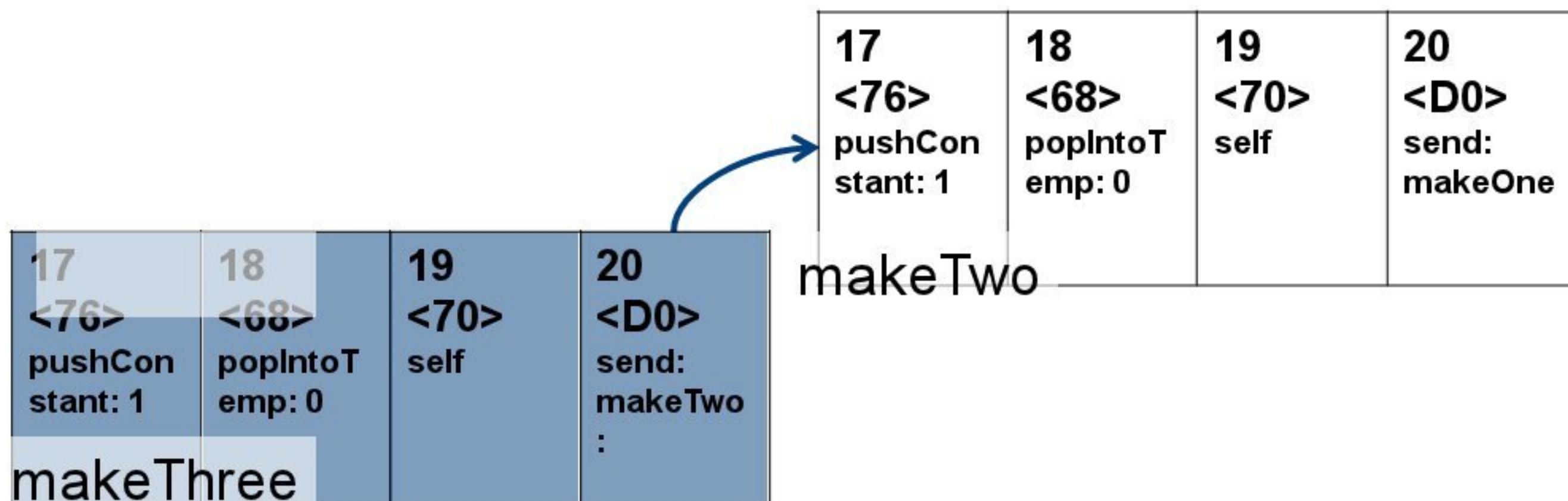
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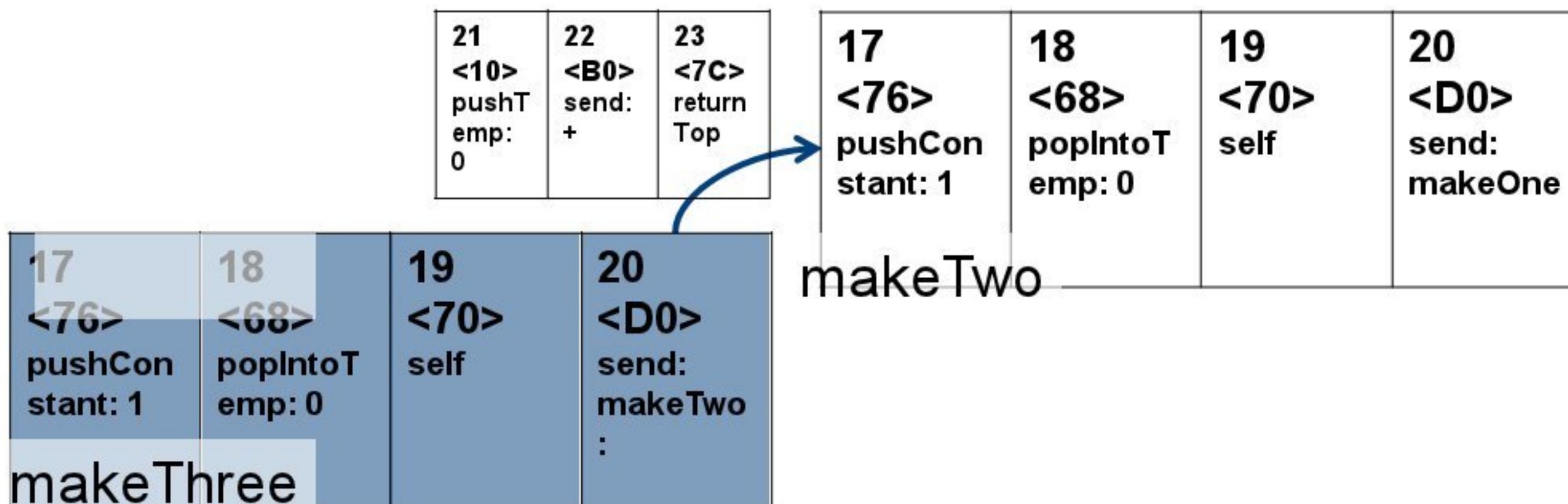
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makeThree			

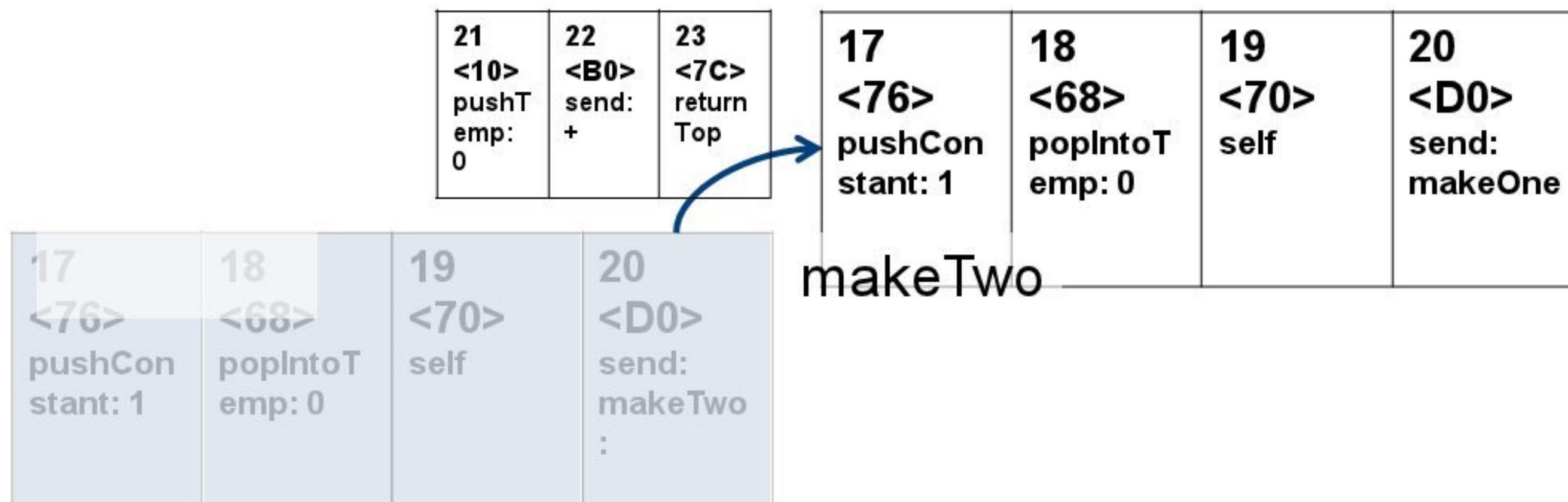
A Program



A Program



A Program



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makeThree (remainder)						
17 <76> pushCon stant: 1	18 <68> popIntoT emp: 0	19 <70> self	20 <D0> send: makeTwo :			

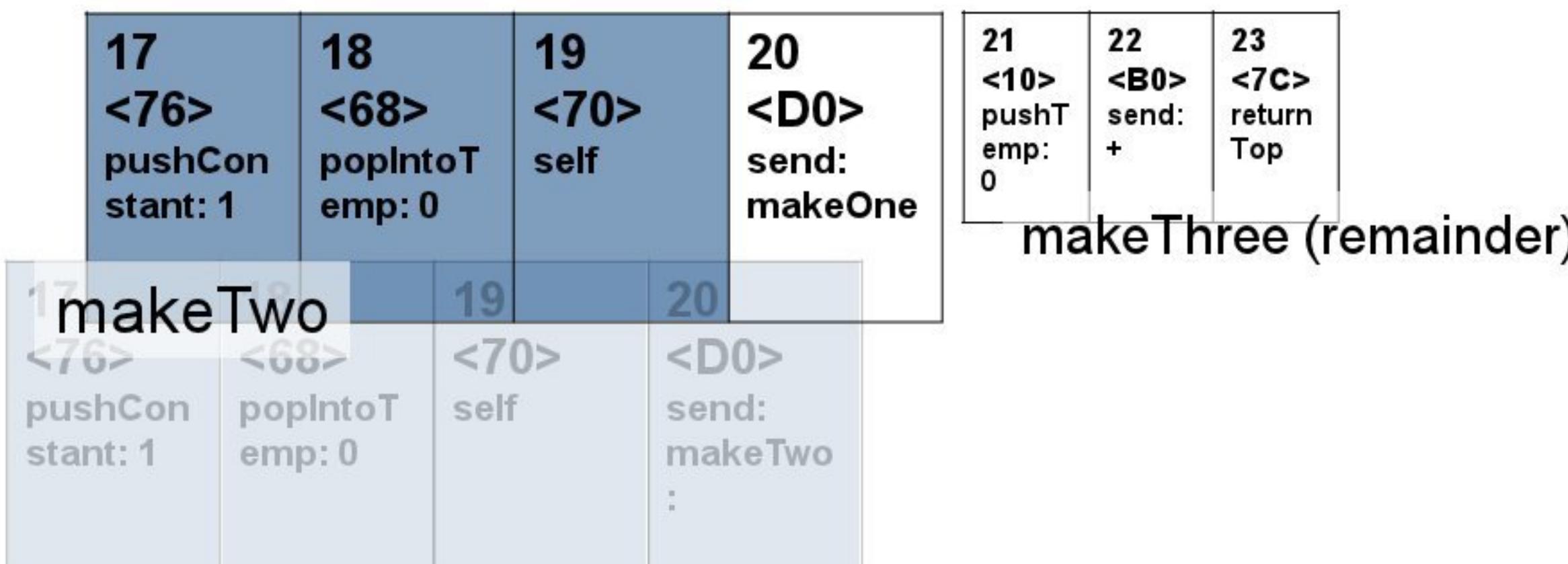
A Program

17 <76> pushCon stant: 1	18 <68> popIntoT emp: 0	19 <70> self	20 <D0> send: makeOne	21 <10> pushT emp: 0	22 <B0> send: +	23 <7C> return Top
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17 makeTwo <76> pushCon stant: 1	18 <68> popIntoT emp: 0	19 <70> self	20 <D0> send: makeTwo :			makeThree (remainder)

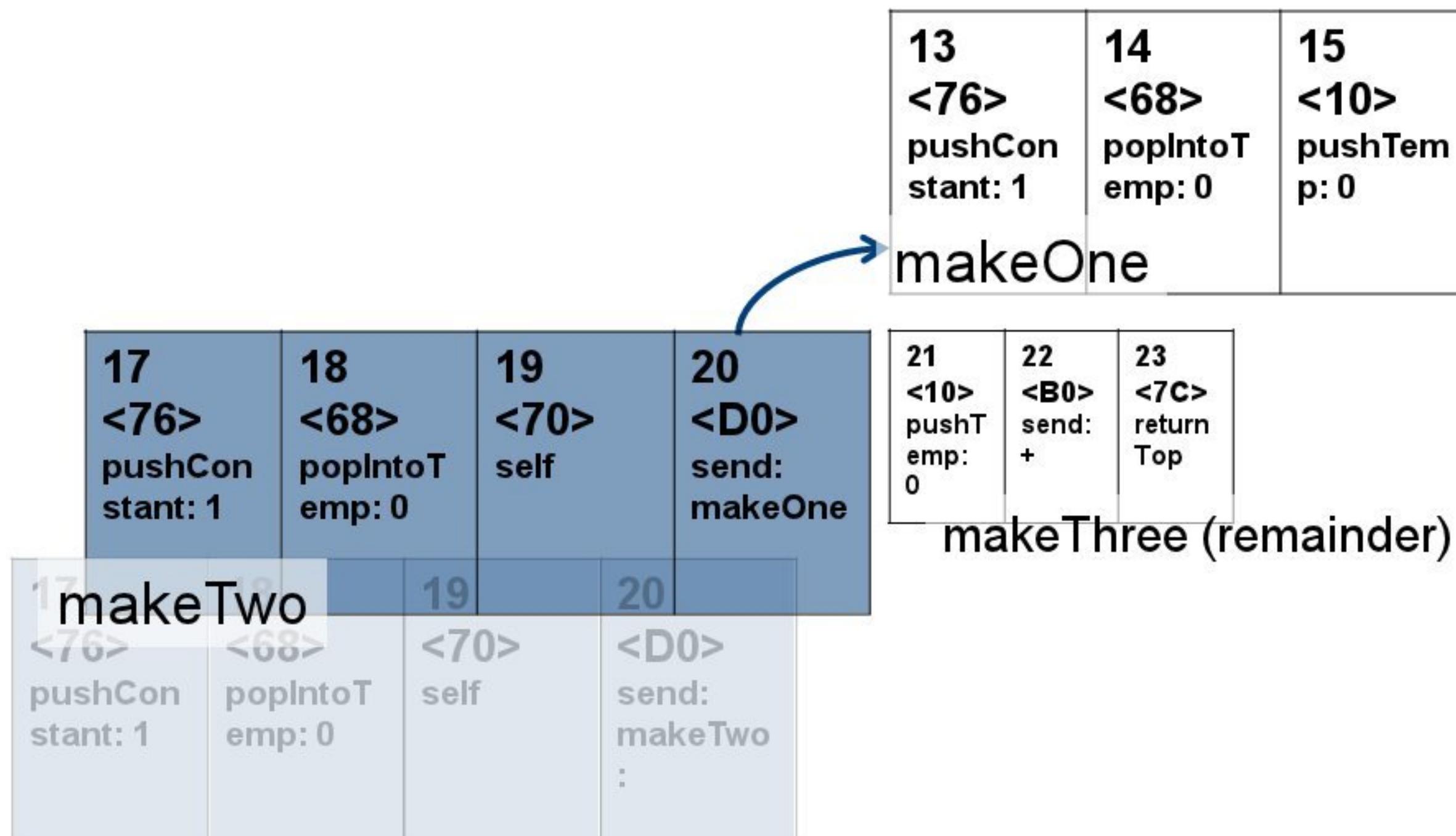
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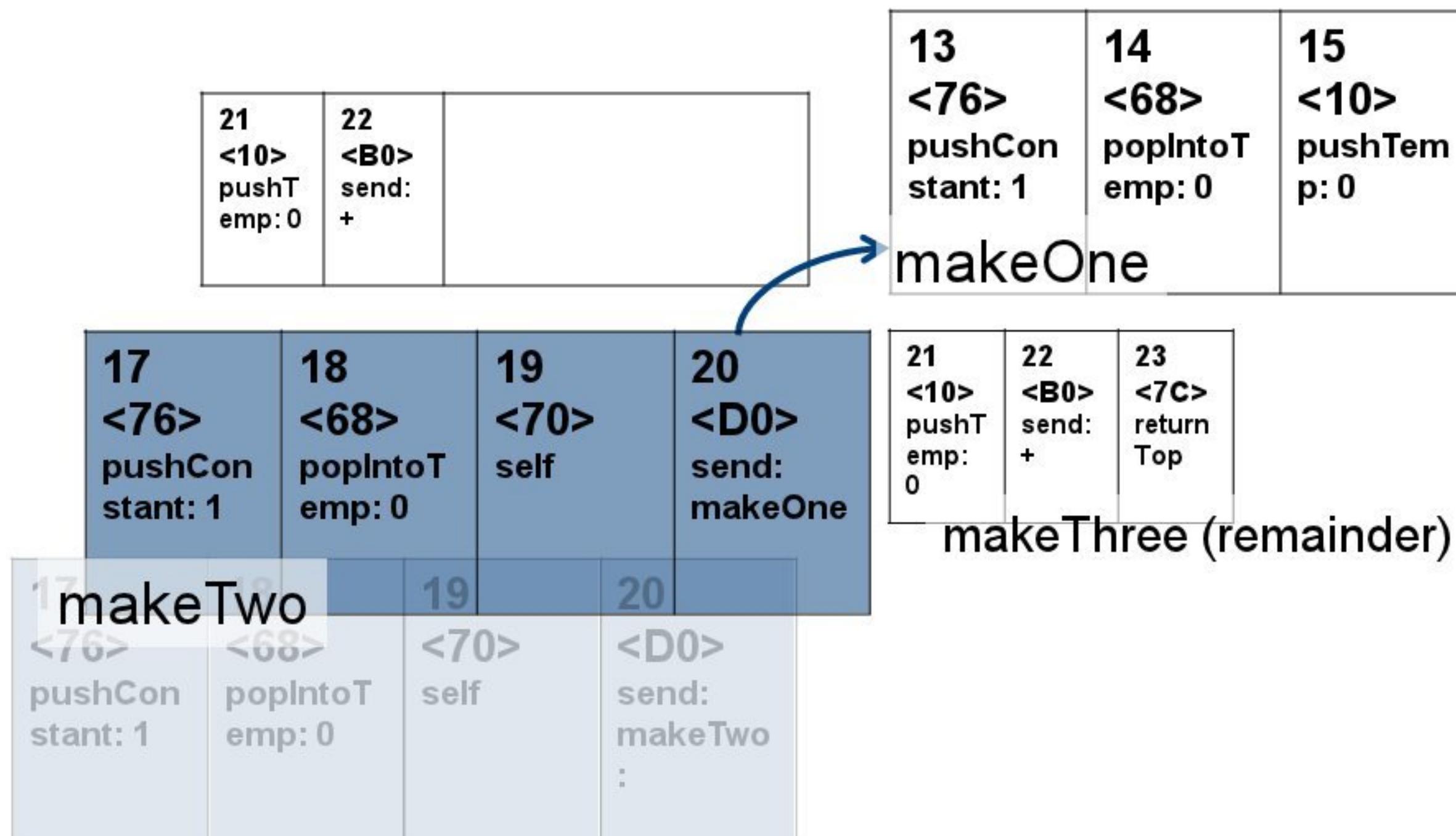
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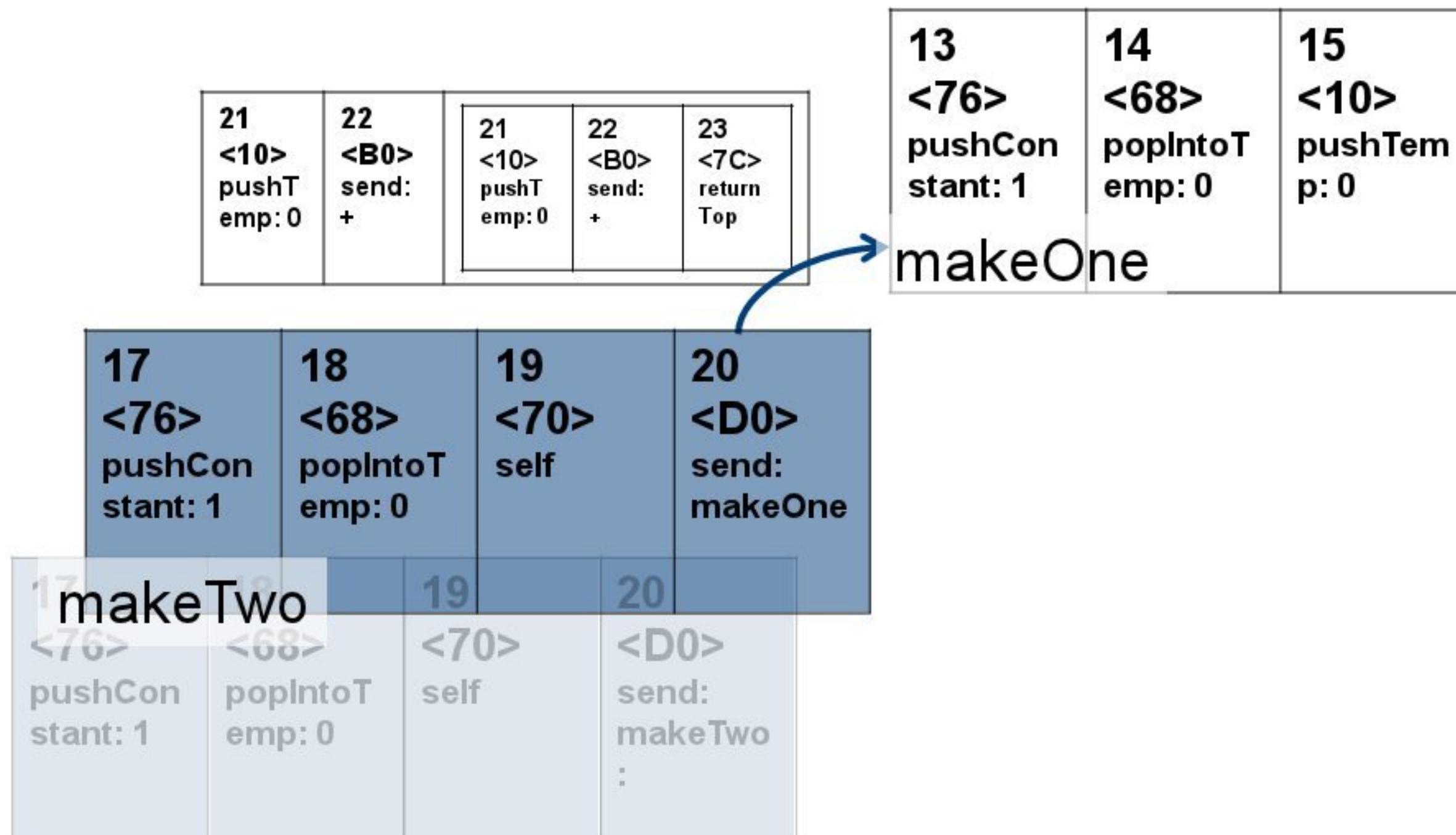
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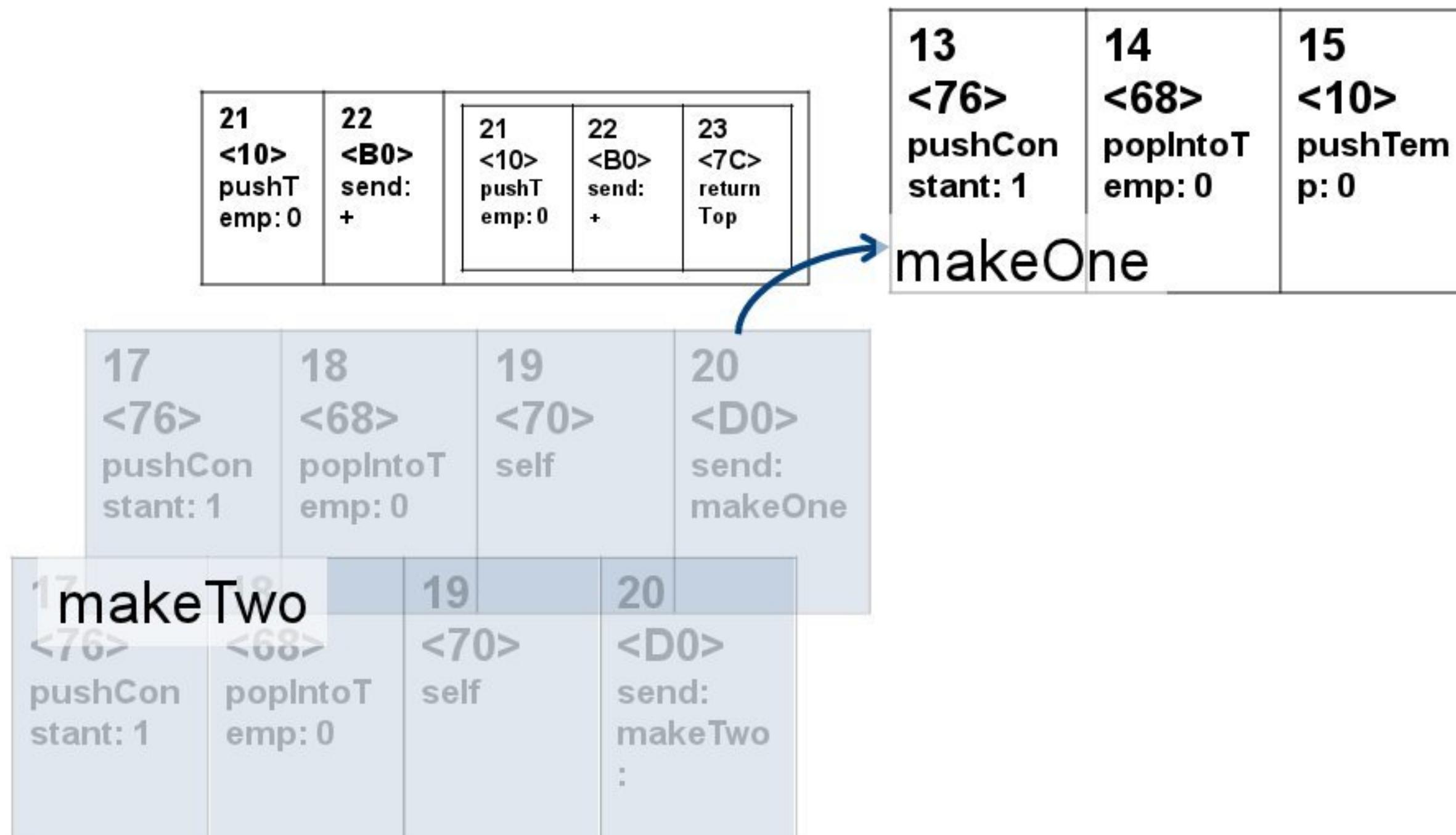
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makeTwo + makeThree (remainders)

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13 <76> pushCon	14 <68> popIntoT	15 <10> pushTem	21 <10>	22 <D0>	21 <10>	22 <D0>	23 <70>
Continuation Passing Style							
17 <76> pushCon	popIntoT	send	send.	makeOne			
constant: 1	emp: 0						
17	18	19	20				
<76> pushCon	<68> popIntoT	<70> self	<D0> send: makeTwo :				
constant: 1	emp: 0						

A Program

13	14	15
<76> pushCon stant: 1	<68> popIntoT emp: 0	<10> pushTem p: 0

21	22		21	22	23
<10> pushT emp: 0	<B0> send: +		<10> pushT emp: 0	<B0> send: +	<7C> return Top

17	18	19	20
<76> pushCon stant: 1	<68> popIntoT emp: 0	<70> self	<D0> send: makeOne

17	18	19	20
<76> pushCon stant: 1	<68> popIntoT emp: 0	<70> self	<D0> send: makeTwo :

A Program

13	14	15
<76> pushCon stant: 1	<68> popIntToT emp: 0	<10> pushTem p: 0

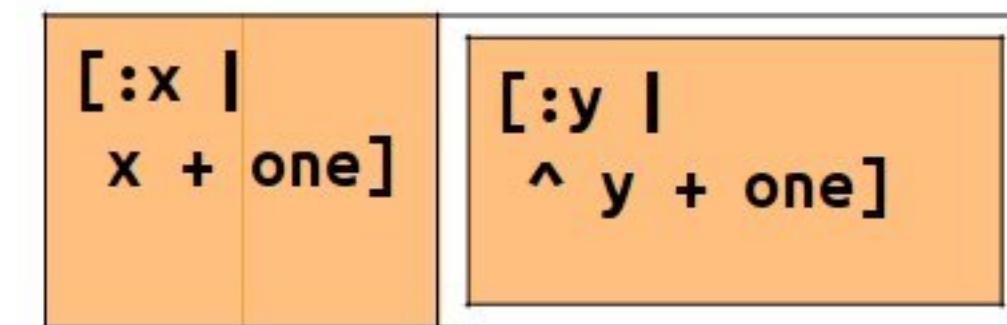
[:x 	x + one]	21	22	23
		<10> pushT emp: 0	<B0> send: +	<7C> return Top

17	18	19	20
<76> pushCon stant: 1	<68> popIntToT emp: 0	<70> self	<D0> send: makeOne

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A Closure/Lambda

- an anonymous function
- an object that can be evaluated

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- an anonymous function
- an object that can be evaluated

```
| name |
name := 'Tim'.
[:greeting | ^ greeting, ' ', name] value
```

A Closure/Lambda

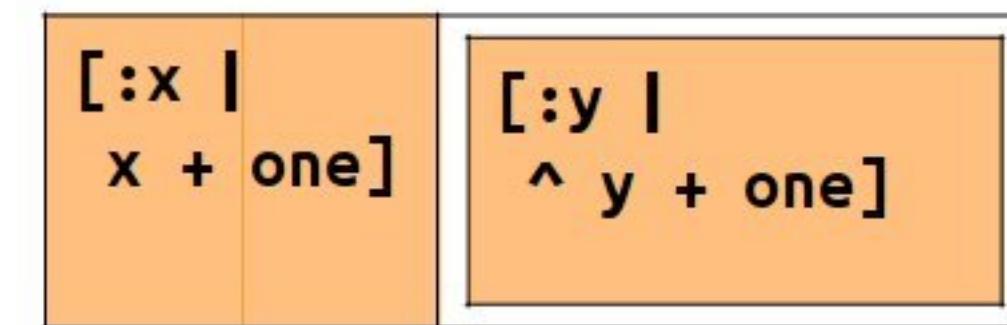
- an anonymous function
- an object that can be evaluated

```
| name |
name := 'Tim'.
[:greeting | ^ greeting, ' ', name] value
```

- 1 argument
 - greeting
- code
 - greeting , ' ' , name
- context
 - {#name -> 'Tim'}

A Program

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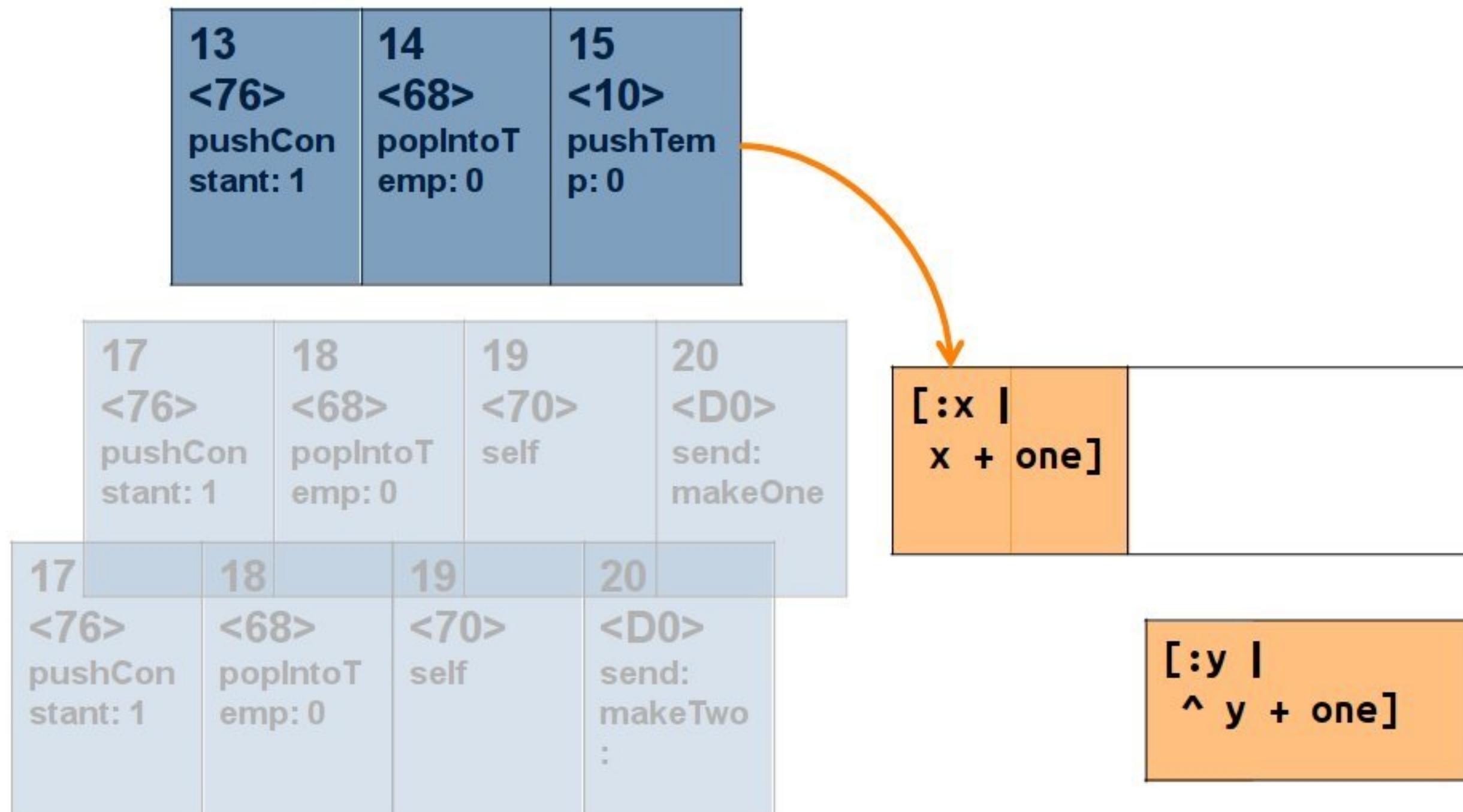
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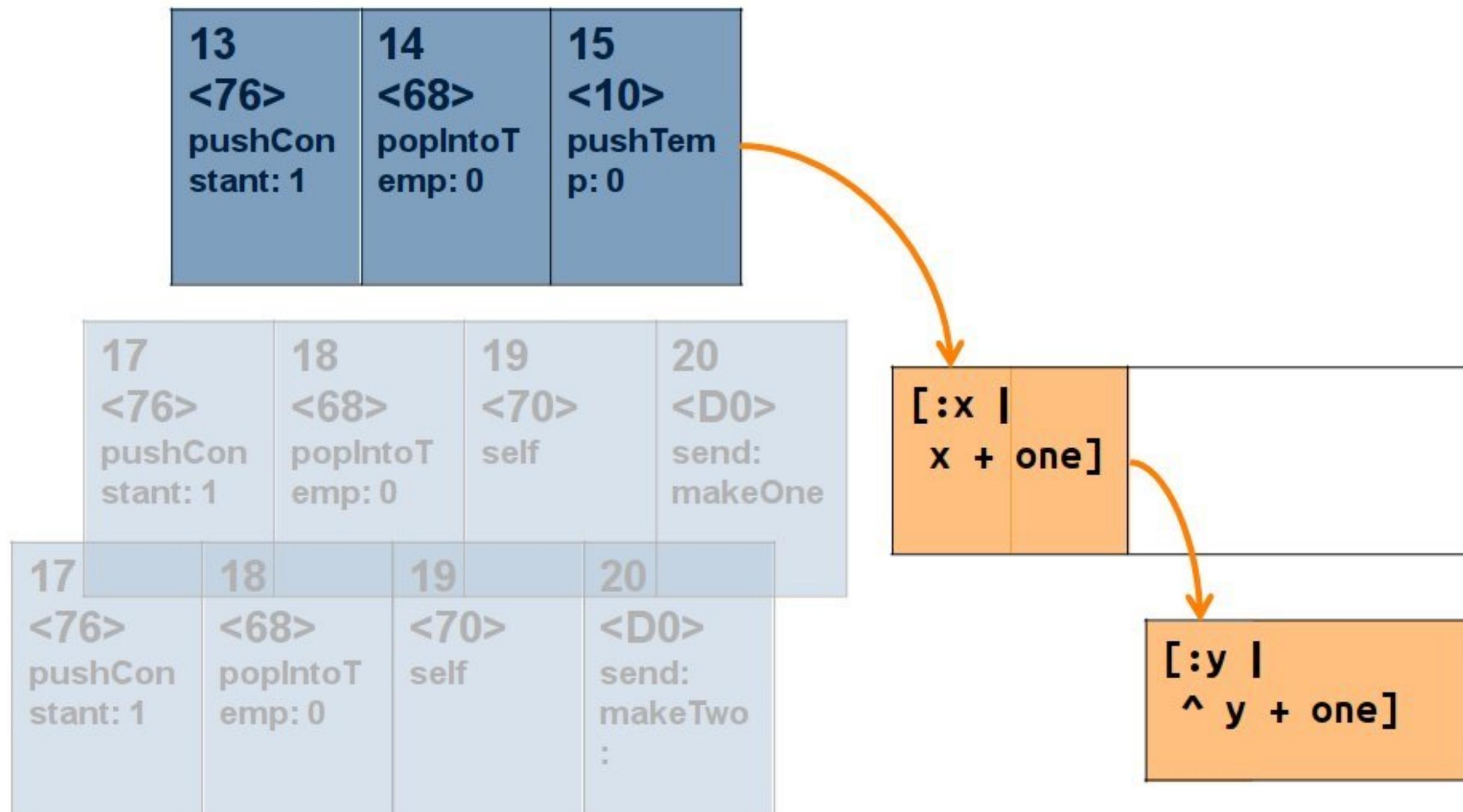
[:x |
x + one]

[:y |
^ y + one]

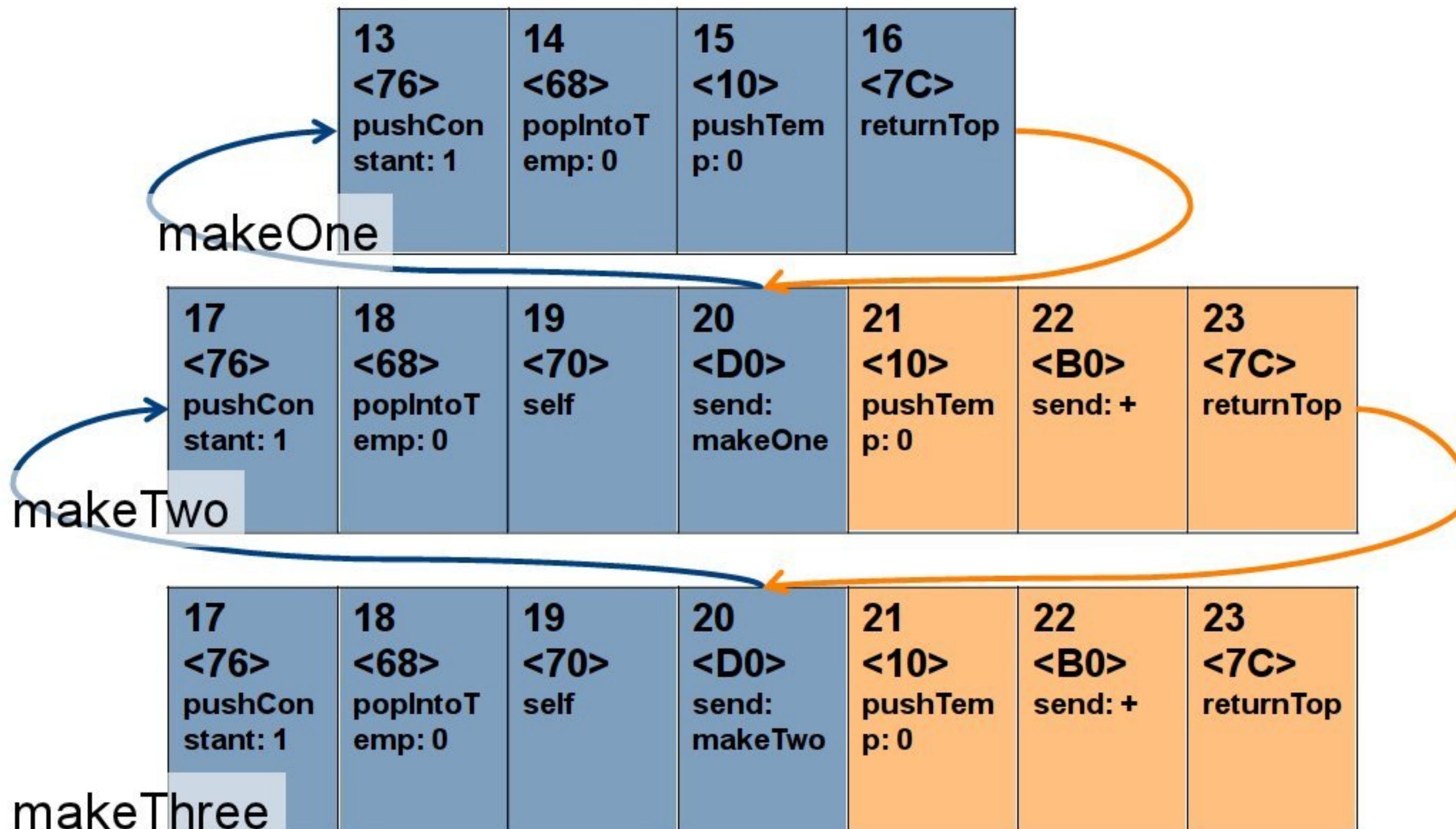
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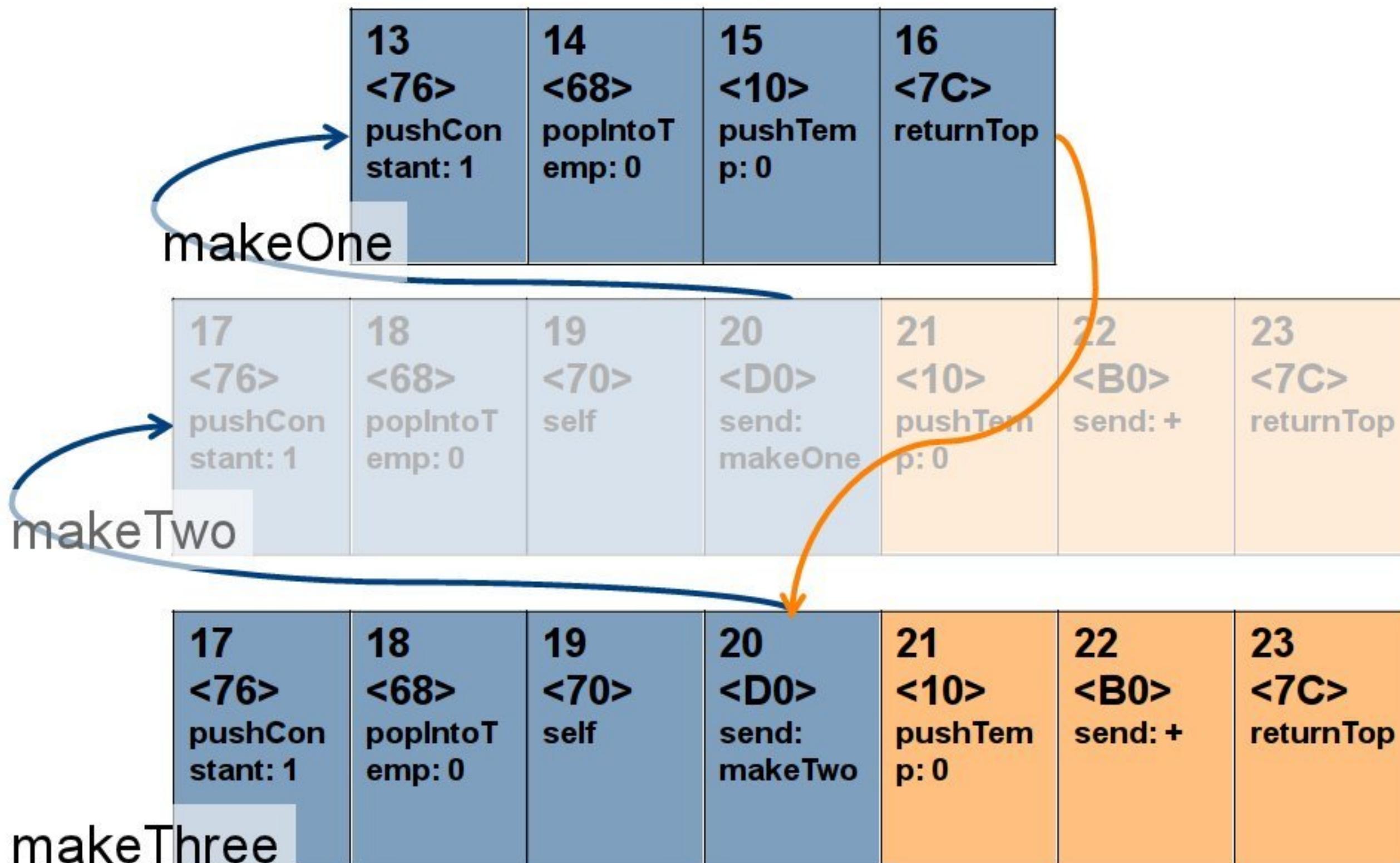
A Program



A Program



A Program



A Continuation

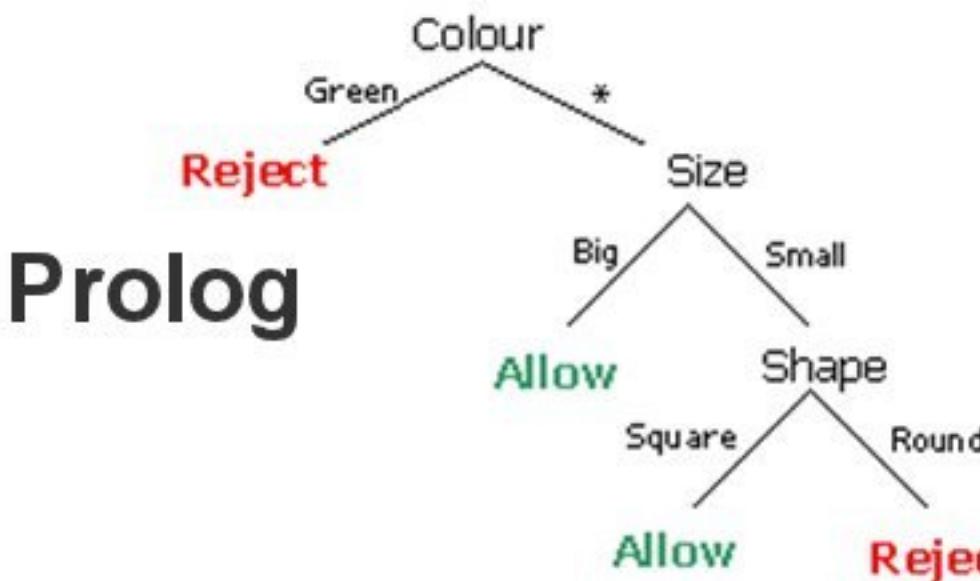
- reification of the execution state in form similar to a closure
 - expects one argument
 - points to a code offset
 - carries the creation context
- contrary to a closure, a continuation returns from the **original creation site**, not to the **caller**
- simple form: exceptions, setjmp/longjmp
 - only from lower stack levels

GOTO, Exceptions, Tail-recursion, Backtracking
DEMOS

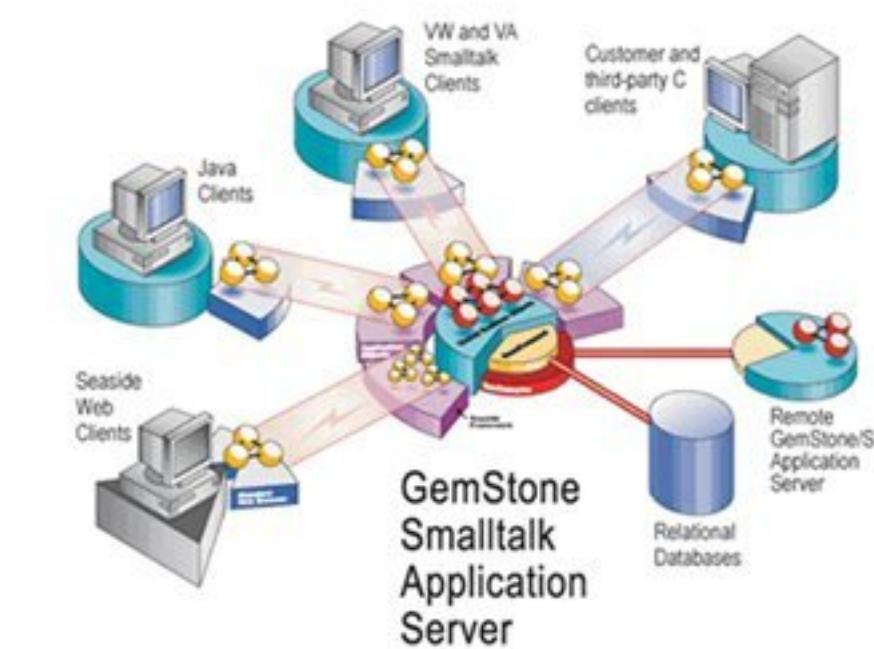
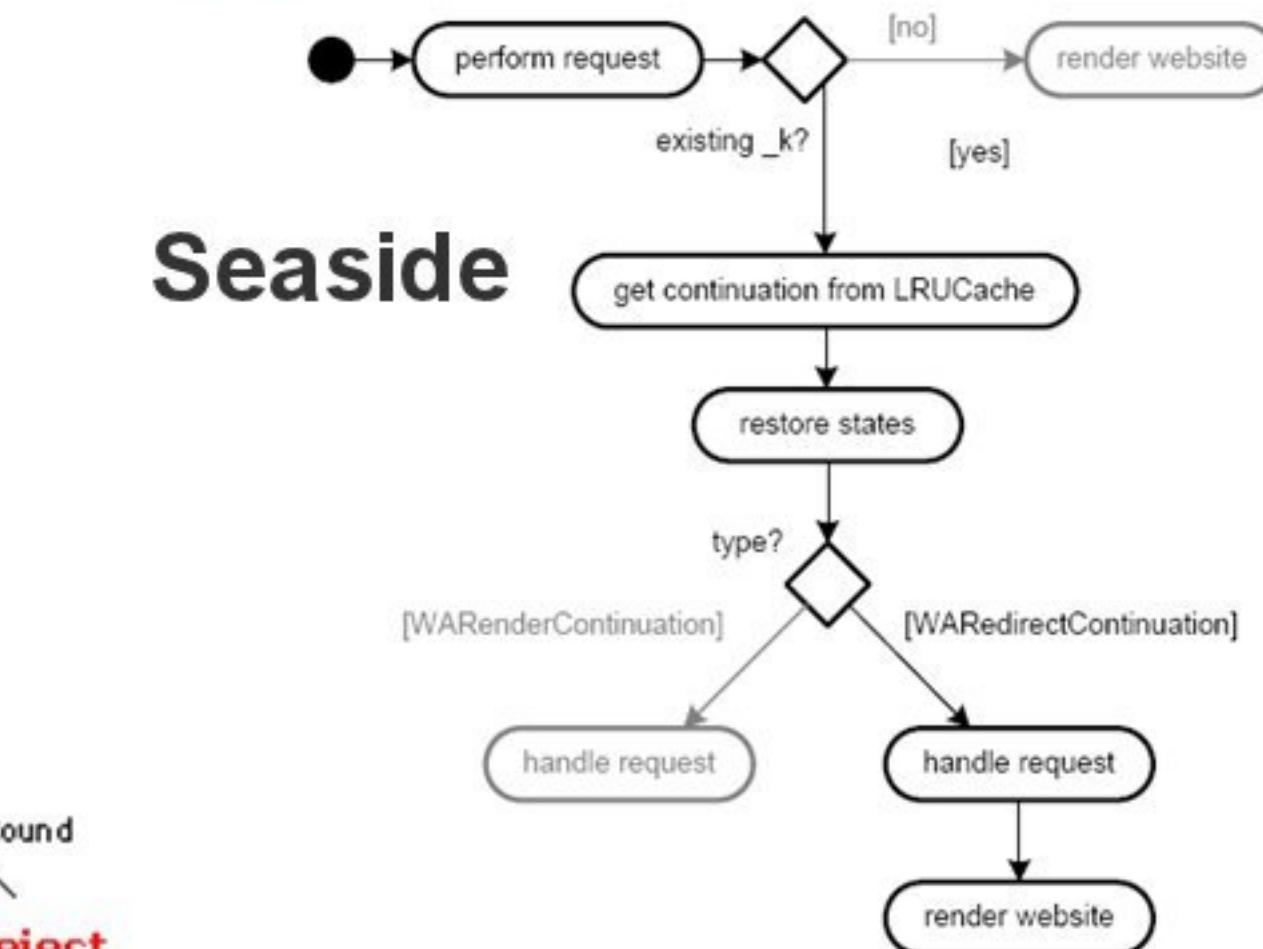
Applications

- co-routines
- co-operative multi-tasking
- generators
- iterators
- worker queues
- parsers
- compilers
- state-machines
-

Higher-level Applications

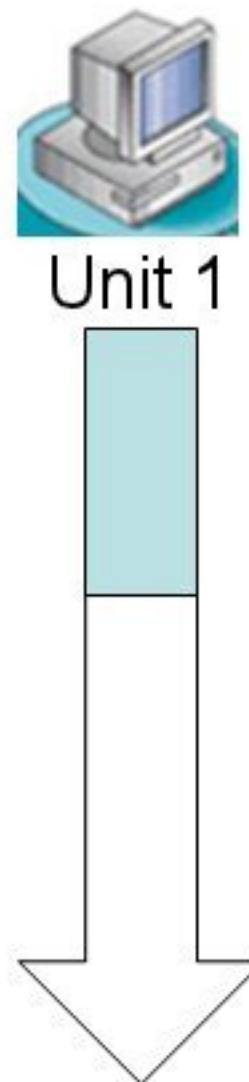


Distributed Computing



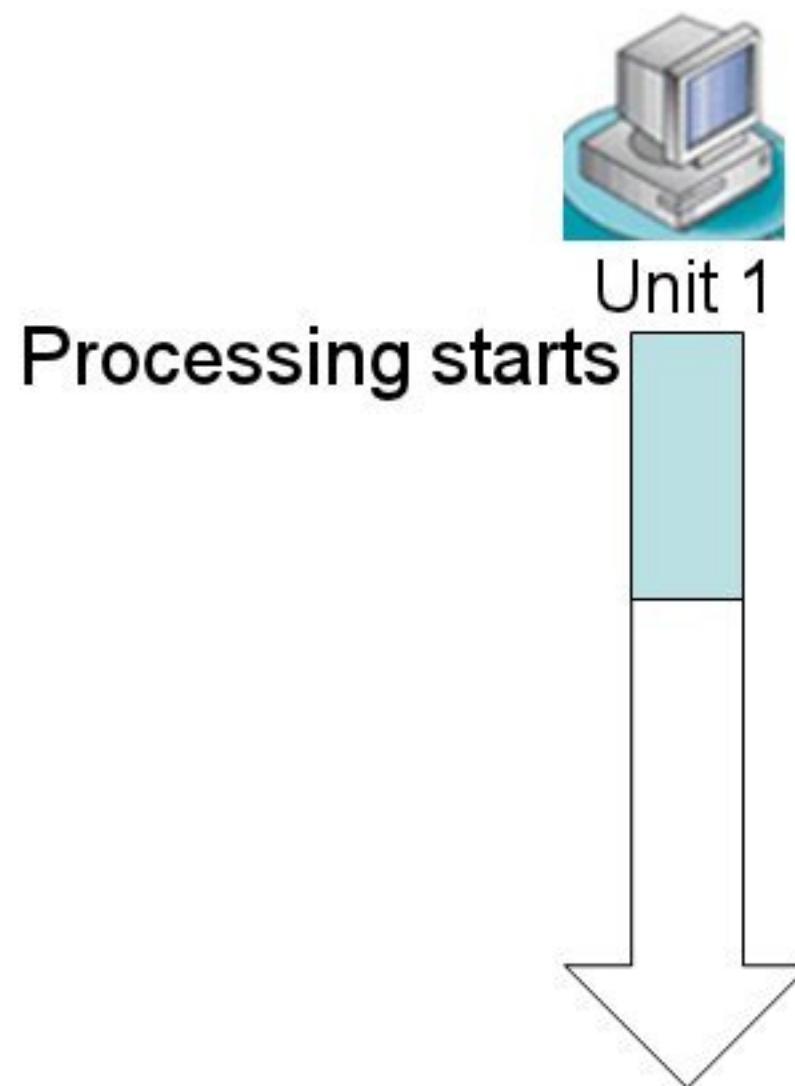
Distributed Computing

- Distributed processing
- Central work queue



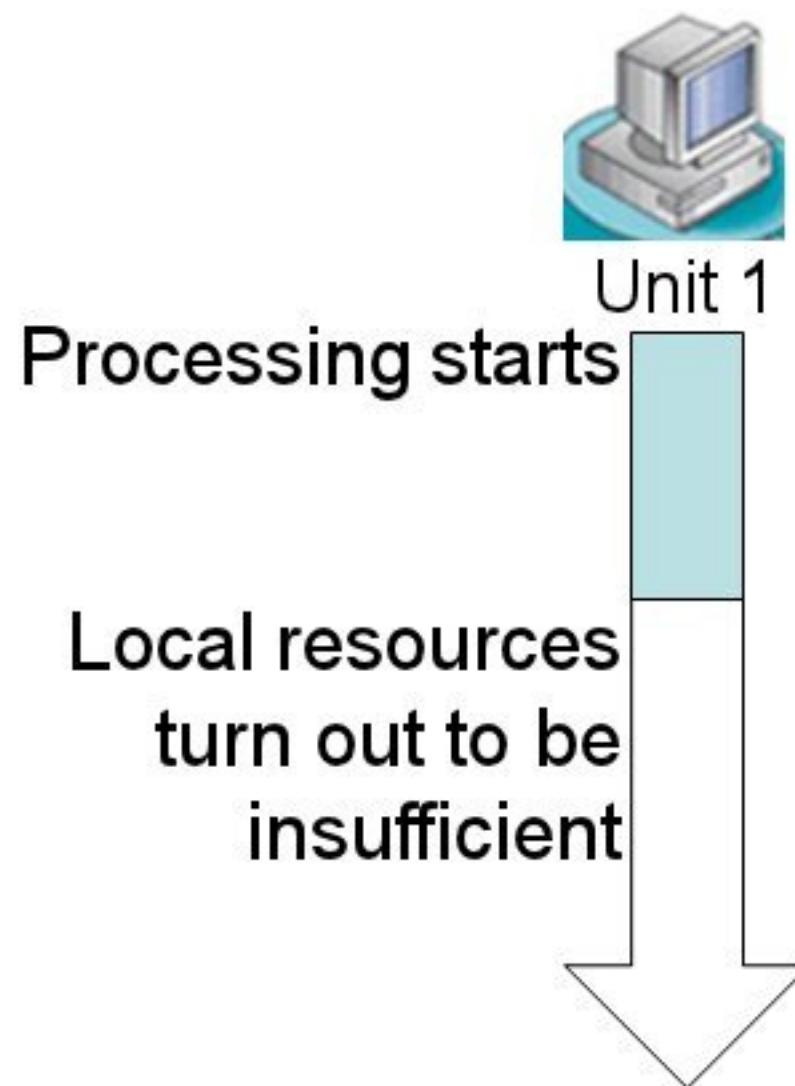
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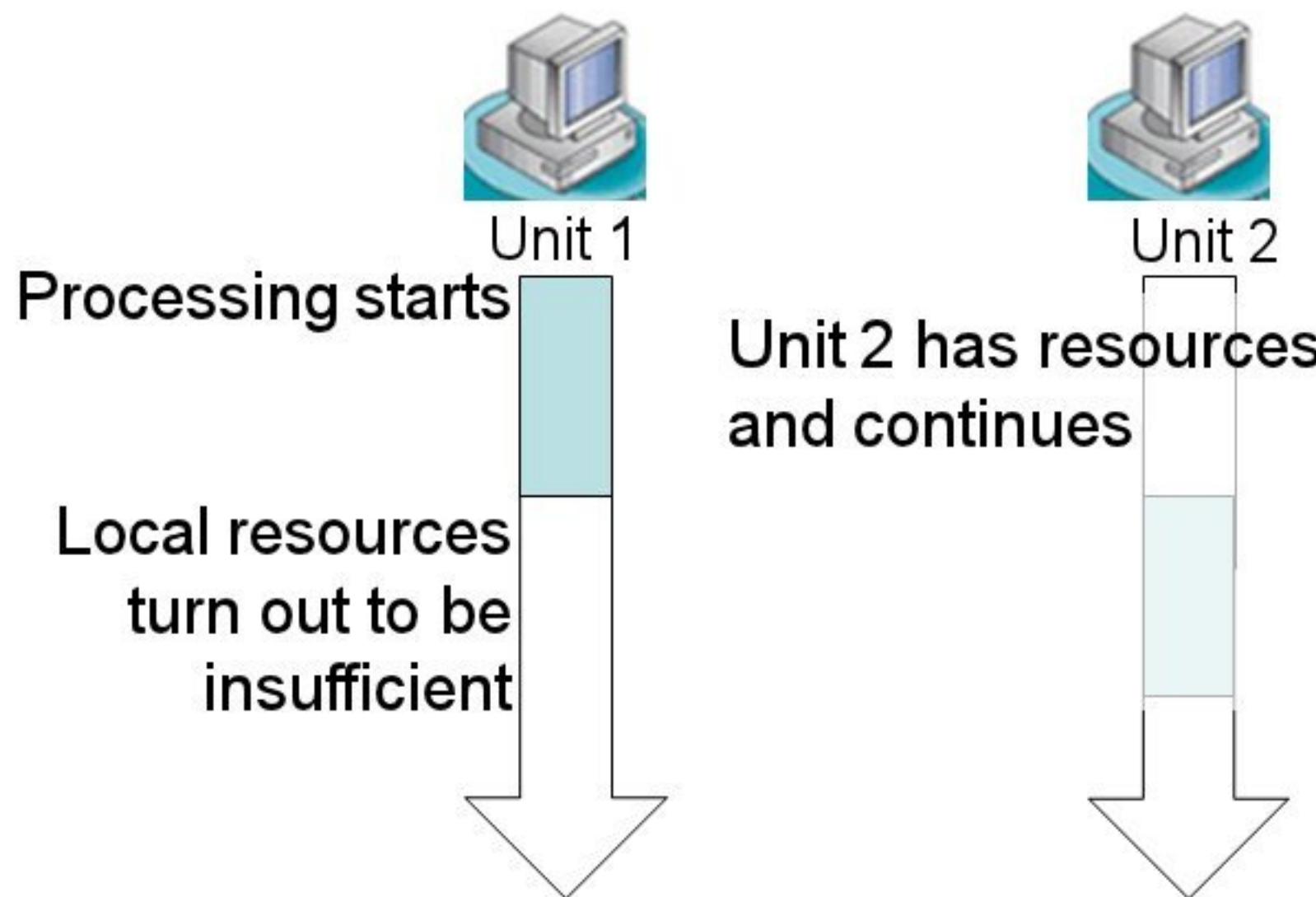
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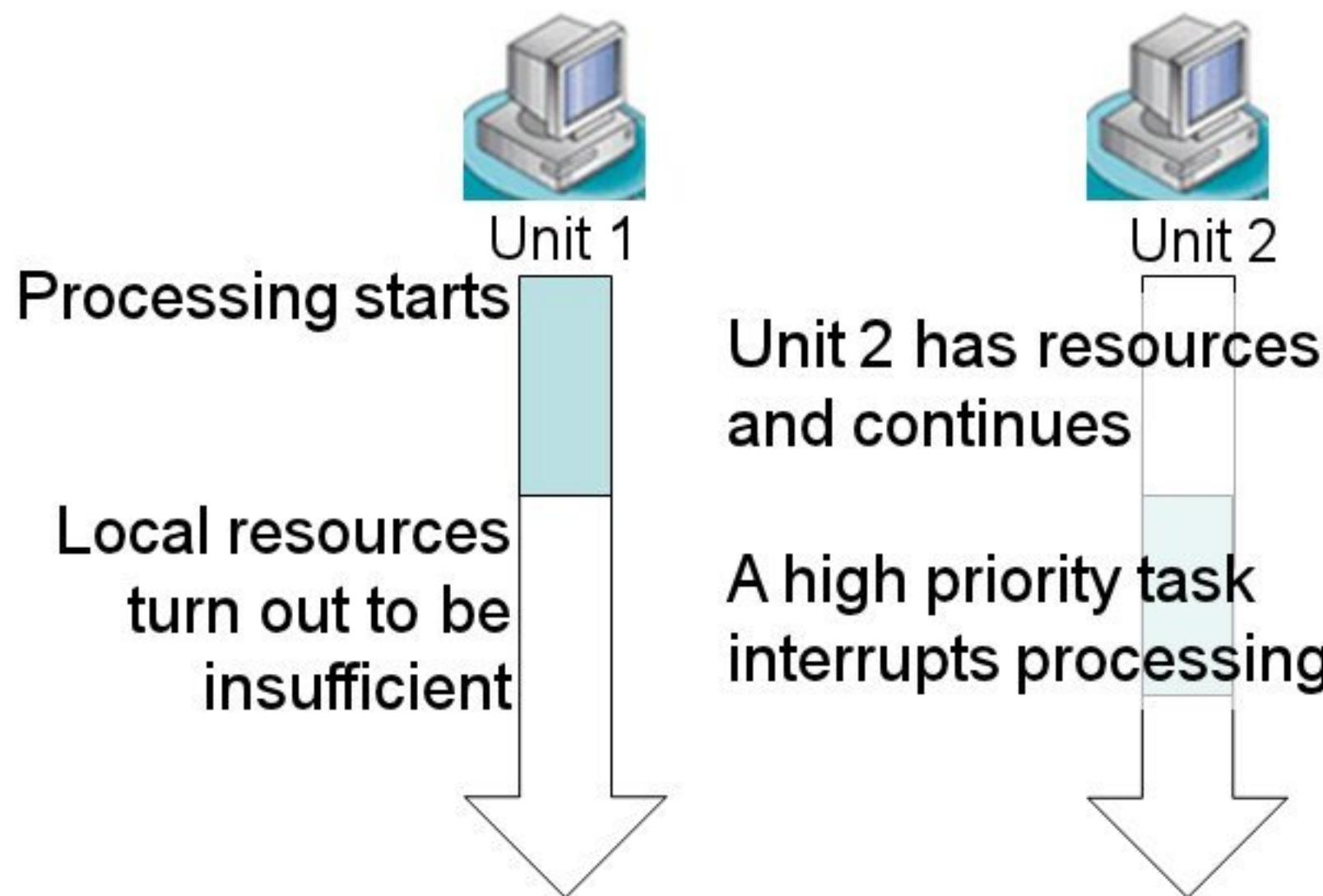
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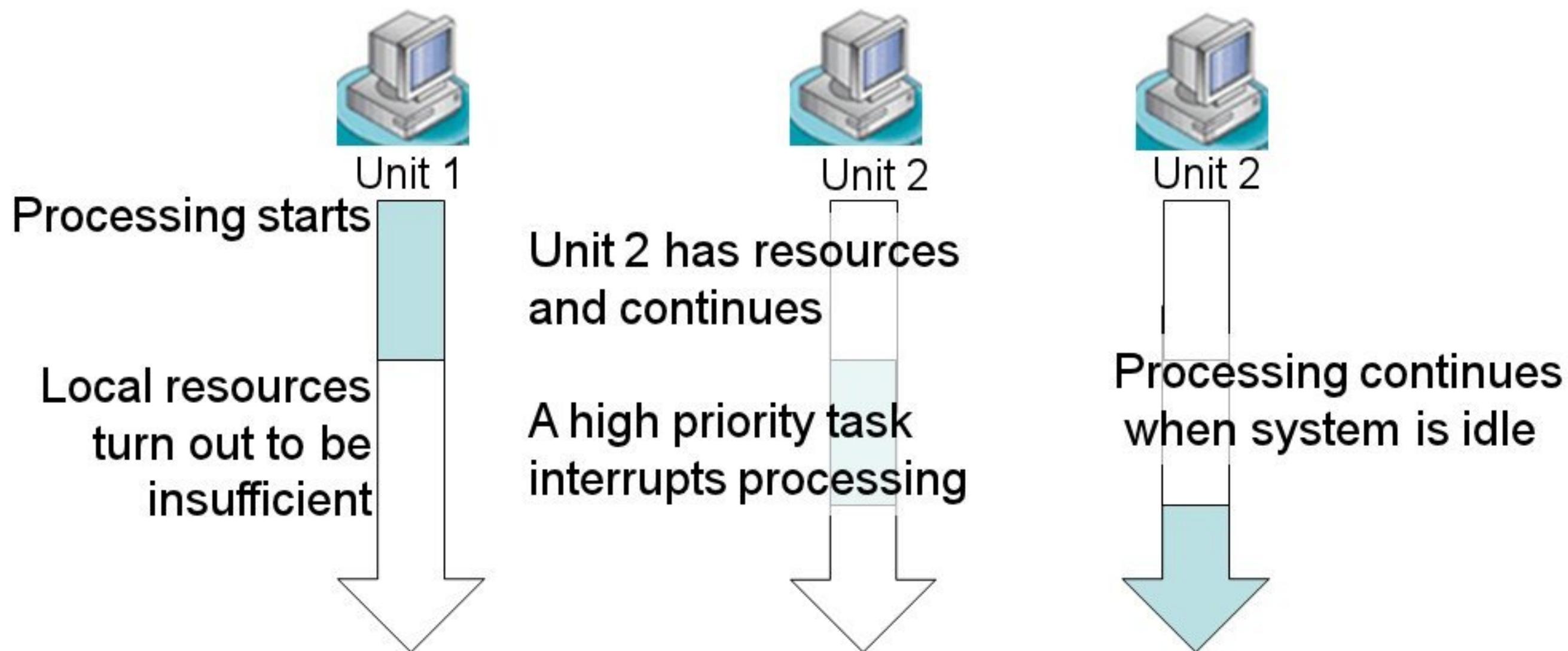
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Distributed Computing

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Conclusions

- Continuations are more powerful than closures or exceptions alone
- GOTO is still considered harmful
- With great power comes great responsibility

References

- Implementation Strategies for First-Class Continuations, W.D. Clinger, A.H. Hartheimer, E.M. Ost
- A Library of High Level Control Operators, C. Queinnec
- Implementing First-Class Polymorphic Delimited Continuations by a Type-Directed Selective CPS-Transform, T. Rompf, I. Maier, M. Odersky
- Shift to control, Chung-chieh Shan
- Scheme R5 Proceedings